The cliffs of the Yellowknife Differentiated Intrusion, looking north.

UNIVERSITY OF ALBERTA

A RECONNAISSANCE: BASIC INTRUSIVE ROCKS OF THE PRECAMBRIAN SHIELD, CANADA

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF GEOLOGY

by

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April, 1965

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "A Reconnaissance: Basic Intrusive Rocks of the Precambrian Shield, Canada", submitted by Alice Payne Leech, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

Samples were taken from diabase dykes and sills and one differentiated intrusive body in four regions of the District of Mackenzie - the Yellowknife - Prosperous Lake area, the Lac de Gras area, the Point Lake area, and the Tree River - Coronation Gulf area, and four regions of Ontario - the Porcupine - Timmins area, the Sudbury area, the Chippewa River (Batchawana) area, and the Pigeon River area.

Radiometric dating by the potassium - argon method indicated at least four periods of diabase dyke intrusion in the Canadian Precambrian shield about 2200-2400 m.y. ago, 1800-2000 m.y. ago, 1100-1200 m.y. ago, and 600-700 m.y. ago. The differentiated intrusive body was emplaced 1900-2000 m.y. ago. Scatter in the radiometric dates, most likely the result of post-intrusion loss of argon, prevents recognition of other possible events. The diabase dykes of the Northwest Territories may be correlated with those of Ontario on the basis of apparent age of intrusion. Periods of basic intrusion in the Canadian Precambrian shield are seen to be comparable to those in Precambrian terranes of other parts of the world. There is some suggestion of an increase in potassium content of dykes throughout Precambrian time. The differentiated intrusion is compared to a similar sheet in east Greenland.

Precise determination of potassium proved difficult: a best value for each sample was finally selected from the results of three independent determinations.

Other petrologic and chemical data indicate that there are no outstanding differences in any of the diabase dykes, all of which belong to the world-wide tholeiitic magma type.

ACKNOWLEDGEMENTS

This thesis is the result of the interest, co-operation and help of many people.

I would particularly like to thank Dr. R. E. Folinsbee for his many kindnesses. His encouragement provided incentive at critical times, and his ideas and suggestions were invaluable. I also wish to thank Dr. H. Baadsgaard and Dr. R. A. Burwash for their many helpful discussions during the course of my work.

The trip to Point Lake and Coronation Gulf was provided by Nahanni Mines Ltd., Toronto, Ontario, and Precambrian Mining Services Ltd., Yellowknife, N.W.T. These companies supplied transportation, food, shelter, and maps. Special thanks are due to Mr. Peter Hudec for giving me the initial permission to make this trip.

Argon extractions and potassium determinations were accomplished under the guidance of Dr. H. Baadsgaard. The necessary glass-blowing was done by Dr. Baadsgaard, who, with Dr. G. L. Cumming, made most of the mass spectrometer runs. The two total-rock analyses reported here, as well as some of the potassium determinations, were done by Mr. Alex Stelmach. All this essential assistance is gratefully acknowledged.

Drafting and photography was done by Mr. Frank Dimitrov. Mrs. Patricia McIntyre and Miss Mae Patterson typed the manuscript.

Finally, I would like to thank my parents, Mr. and Mrs. Thomas Payne, for their constant support, and my husband, for his understanding and patience.

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INTRODUCTION

Areas of Study

This work began as a study of a differentiated intrusive body at Yellowknife, in the District of Mackenzie, but was subsequently expanded to include the investigation of the belts of diabase dykes and sills in several other areas of the District of Mackenzie and Ontario. The dyke sets, which may be up to 200 miles wide, are very persistent over long distances and follow characteristic trends.

Field work was done near Yellowknife during the summer of 1963, when the author accompanied a departmental field trip to the area. The differentiated intrusion, lying to the east of Yellowknife Bay, was surveyed and sampled, and a 158-foot drill core obtained from it. In addition, a few samples were taken from the diabase dykes of the area.

In the summer of 1964, the diabase dykes in the Yellowknife-Prosperous Lake area were sampled more comprehensively. An opportunity was provided to visit prospecting camps at Point Lake, 200 miles north of Yellowknife, and an unmapped lake 200 miles further north of Point Lake, near the Tree River and Coronation Gulf. This resulted in further dyke sampling and an enlargement of the study area. In the same year, during a trip through Ontario, samples of basic dykes and sills from the Sudbury area, the Chippewa River area, north of Sault Ste. Marie, and the Pigeon River area, south of Fort William-Port Arthur were collected.

The areas of the District of Mackenzie, Northwest Territories, are outlined on G.S.C. Map 1055A (in pocket) and an index map of the Ontario sampling locations is given in Figure 4, p. 17.

The study areas also included the Lac de Gras area, about 150 miles northeast of Yellowknife, and the Porcupine - Timmins area, of Ontario. All of the Lac de Gras samples and the Porcupine - Timmins samples (and some of the Yellowknife samples) were not collected personally but were furnished through the kindness of others.

Purpose of Study

The purpose of this study was to contribute to the understanding of the nature of basic intrusion in the Precambrian shield. In order to accomplish this, an attempt was made to establish the ages of intrusion of the basic rocks, investigate their composition, and classify them according to basalt magma type. The results of the detailed work in the Yellowknife - Prosperous Lake region were applied in the interpretation of results from the other scattered areas.

Potassium - argon whole-rock dates were obtained from the basic rocks of all the areas sampled. From these dates, it was possible to suggest periods of basic intrusion during Precambrian time. In addition, this dating survey provided some insight into the general usefulness of potassium-argon whole-rock dating of basic rocks.

Petrologic studies of thin-sections of the intrusions in the District of Mackenzie made possible a modal estimation of their composition and aided in the interpretation of the radiometric dates.

Chemical and x-ray - fluorescent analysis established the total alkali and silica contents of the rocks, which were then classified as belonging to the tholeiitic basalt type. Two complete analyses were available for the Yellowknife differentiated intrusion, and its normative composition calculated. Determinations of potassium were made by three different methods (in conjunction with the radiometric dating work), and this gave a valid comparison of analyses done routinely, but carefully, by different means.

These basic intrusions of the Canadian Precambrian shield were considered throughout this study in relation to other Precambrian and Phanerozoic basic intrusions of the world. The Precambrian basic intrusions are found to be closely related in time and tectonic setting.

GENERAL GEOLOGY

DISTRICT OF MACKENZIE

Sampling of basic dykes and sills has been accomplished in four regions in the District of Mackenzie - the Yellowknife-Prosperous Lake area, the Lac de Gras area, the Point Lake area, and the Tree River-Coronation Gulf area.

These several areas of the Slave province resemble one another closely: the rock types are similar in character, and the various regions have undergone major periods of intrusion at about the same time. The dykes of each area show the same general mode of occurrence and distribution, and give indications of several periods of intrusion over large areas.

The east half of Map 1055A (in pocket) published by the Geological Survey of Canada (1958) covers all these areas, which have been outlined on it.

Yellowknife - Prosperous Lake Area

Comprehensive descriptions of the general geology of the Yellowknife Bay - Prosperous Lake area have been made by several writers. Reports by Stockwell and Kidd (1932) and Stockwell (1933) were followed with three by Jolliffe (1936, 1938, 1945). The two maps published in 1942 and 1946, based on Jolliffe's geological interpretations remain the most useful maps of the area. Henderson and Brown worked for several seasons, producing a series of preliminary maps, (1948, 1949, 1950, 1952) that culminated in descriptions of the structure and geology of the Yellowknife Greenstone belt (1950b, 1952b). A publication, "Geology and Structure of the Yellowknife Greenstone Belt, Northwest Territories", by Henderson and Brown is in press and will appear as Bulletin 141 of the Geological Survey (pers. comm., J. F. Henderson). Interest in the gold deposits of the District of Mackenzie, especially in the Yellowknife area, resulted in two major publications (Lord, 1951; Boyle, 1961) that give comprehensive summaries of the Yellowknife - Prosperous Lake area as well as the surrounding region. Most of these reports describe the diabase or gabbro

dykes and sills that intrude the older Precambrian rocks, and are the latest consolidated rocks. The table of formations (Table 1) follows the one suggested by Henderson and Brown (1952b).

The rocks of the Yellowknife Group have been divided into two divisions. The oldest rocks (Division A) consist of a series of dark green weathering massive and pillowed flows, mostly andesites and basalts, but with some interbedded dacite, chert, tuff and agglomerate. Primary structures are preserved; some of the flows are variolitic and can be traced throughout the entire greenstone belt. Division B rocks consist of mainly sediments, with acid lava flows and derived conglomerate in the basal section. Arkose, quartzite, argillite, and pyroclasts, as well as greywacke and slate complete the section. The rocks have been metamorphosed to slates, phyllites, and schists, the grade increasing as intrusive granites are approached. The nature of the contact between rocks of Division A and Division B is in doubt. In the Yellowknife area, a granite - pebble-bearing conglomerate may be found along the west margin of Yellowknife Bay and on the south shore of Duck Lake, resting with angular unconformity on the lavas of Division A. Elsewhere, the two divisions appear to be conformable. To the north, faulting and drift complicate the situation and it has been suggested (Henderson and Brown, 1952) that these conglomerates are younger than the Yellowknife series.

The oldest intrusive rocks are gabbro and diorite sills, dykes, and irregular masses, which are chilled against the older volcanics and each other, and are in turn cut by quartz-feldspar porphyry. The basic intrusives are to be found mainly in the volcanics of Division A, although a few sills are mapped as part of Division B. In the north, the conglomerate truncates several dykes.

The granitic rocks in the area intrude all the above, and are divided into two units, the Prosperous Lake granite, and the masses (with their associated stocks, dykes and aplites) flanking the greenstone belt on the west and southeast. The Prosperous Lake granite was considered the younger. Folinsbee (1955) reached the

TABLE 1

TABLE OF FORMATIONS

Era	Formation	Lithology	Age of Metamorphism and Intrusion (m.y.)
Cenozoic		sand, gravels, clays	
UNCONFORMITY			
Proterozoic		diabase, gabbro	various
INTRUSIVE CONTACT			
Archaean		granite, granodiorite, quartz diorite, diorite, aplite	2615-2540
INTRUSIVE CONTACT			
		quartz feldspar porphyry	
INTRUSIVE CONTACT			
		gabbro and diorite dykes and sills	
INTRUSIVE CONTACT			
	Yellowknife Group Division B	arkose, greywacke, tuff, conglomerate, interbedded dacite, trachyte, rhyolite, quartz porphyry, tuff, agglomerate	
UNCONFORMITY ?			
		*conglomerate and quartzite	
UNCONFORMITY			
	Division A	(basalt, andesite),dacite, chert, tuffs,agglomerates	

* Conglomerate and quartzite which rest with angular unconformity on Division A, but have an unknown relationship to Division B rocks.

conclusion that there was no significant difference in age between the two granites, and this was later confirmed by others (Lowdon, 1961; Lowdon et al. 1963).

Both the rocks of Division A and B have been metamorphosed - the basic volcanics are altered to amphibolites, the acid volcanics carbonatized, and the sediments show various degrees of metamorphism from slates and phyllites to knotted schists. The regional facies are related to the granite contacts.

The diabase dykes and a composite gabbro intrusive are the youngest consolidated rocks in the area. They are shown on the Yellowknife - Prosperous Lake Area map in the pocket.

With respect to structural deformation, the volcanic rocks have been folded into steeply-dipping simple folds, while the sediments have yielded by isoclinal folding and cross folding. In addition to this folding, the rocks of the area have been subjected to frequent periods of intense faulting. The fault and fracture patterns have been classified as two types, pre-diabase and post-diabase. Pre-diabase faults and fractures are of several ages: early pre-shear zone fractures, found mostly in the greenstones (but also in the granite) tend to strike N 20°W - N 40°W. The chloritized shears themselves strike N - NE and dip to the west. Later, pre-diabase fractures cut the shear zones only, and have variable strikes. In the sedimentary rocks, the faults and fractures can be related to the complex, severe folding and cross folding. The post-diabase faults are of much greater magnitude and do not have shear zones associated with them, although they may have a brecciated zone along the strike. Seven major faults, with "cross over faults" between them, can be found in the Yellowknife - Prosperous Lake area, striking N - NW, dipping vertically, and having left hand movement.

Post-Archaean Dykes and Sills:

At first, the dykes and sills in the east arm of Great Slave Lake attracted more interest than the less spectacular group in the Yellowknife area. Dykes of

quartz and olivine diabase and a composite gabbroic intrusion intrude all the other Precambrian rocks in the Yellowknife-Prosperous Lake region. The dykes weather a rusty brown color (from a grey mottled fresh surface), vary in width from a few inches to a few hundred feet, and persist over long distances. They are vertical or steeply dipping, and in this area, three trends are apparent (Burwash et al. 1963): N 70° - 80°E, N 0° - 30°E, and N 45° - 60°W. These will hereafter be referred to as Set I, Set II, and Set IV respectively.

Most of the dyke contacts are chilled against the country rock, and are fine-grained. Some are composite, with internal dykelets chilled against the major dyke. In areas of fine-grained basic volcanic rocks, a contact is very difficult to find. A slight baking of the wall rock near the contact is often all that is apparent. The dyke centres, which are medium to coarse-grained, show the characteristic diabasic texture, with laths of basic feldspar in a groundmass of pyroxene. Amounts of feldspar and pyroxene are about equal. Wilson (1949) made a petrographic study of the dykes and found no major differences, in examining thirty sections from various locations.

The cross-jointed dykes, with their reddish weathered surface, are easily spotted in the field, but they tend to weather into muskeg or water-filled depressions, and critical outcrops of cross-cutting contacts are scarce. Dyke intersections in the field have been reported by Campbell (1948) by Wilson (1949) and by Henderson and Brown (1952). In most cases, the contacts show that dykes of the N 0° - 30°E set cut the N 45° - 60°W set, but a few exceptions exist.

The dykes were all assigned to the "late Precambrian" on the basis of observations at Yellowknife - Prosperous Lake and in the east arm of Great Slave Lake. In the east arm, diabase dykes and sills were found cutting the Et-Then series and all older rocks (Stockwell and Kidd, 1932; Stockwell, 1933). The idea of essentially contemporaneous age (and source) of intrusion was unchallenged until 1963 when Burwash et al. suggested at least two ages of intrusion in this area,

1800-2400 m.y. for Set I, and 1400-1600 m.y. for Set II of the Yellowknife Area. Set IV was not dated.

The other basic intrusive of importance in the Yellowknife - Prosperous Lake area is a composite intrusion body (pictured in the frontispiece) of Yellowknife Bay. From the Yellowknife River south to Duck Lake there is an almost continuous outcrop of this rock mass. The Akaitcho fault cuts off further exposures to the south for 5 miles, where a 3 mile continuation of the body reappears, on the west side of the fault. The intrusion strikes north-south, appears to dip at a low angle to the east and is faulted throughout. Nowhere is a complete section found. The olivine gabbro shows primary banding, and columnar jointing, which may be easily seen in the northern exposures where 80 foot cliffs dominate the generally low lying terrane. At various places the transition zone from lower olivine gabbro to upper quartz gabbro and the upper contact may be seen but the lower contact was not found. Near the contacts, the sediments have a baked appearance for up to 30 feet from the contact. The petrology of this intrusion was discussed by L. S. Hill in 1940 in a M.Sc. thesis submitted to McGill University. With respect to age, the intrusion was assigned to the late Precambrian, on the basis of its suspected close relation in time to the diabase dykes.

Samples of dykes of several trends as well as samples of the composite intrusive body were taken. Precise sample locations are given in Appendix A; general sample locations may be found on the Yellowknife - Prosperous Lake Area map (in pocket).

Lac de Gras Area

This area is separated from the Yellowknife - Prosperous Lake area by at least 100 miles, over half of this distance being occupied by granite. In general, the rocks are of the same type. Stockwell (1933) described rocks similar to his Point Lake - Wilson Island group, which Henderson (1938) renamed the Yellowknife group, but the area was not thoroughly mapped until later (Folinsbee, 1949). The Yellowknife group here is made up of a thick series of volcanic rocks overlain, apparently conformably,

by sediments with some lavas near the base of the succession. The oldest volcanics are mostly andesites and basalts with some late dacite and rhyolite and associated tuffs and agglomerate. They have been intruded by basic sills and dykes. The overlying sediments were originally arkose, shale, and greywacke.

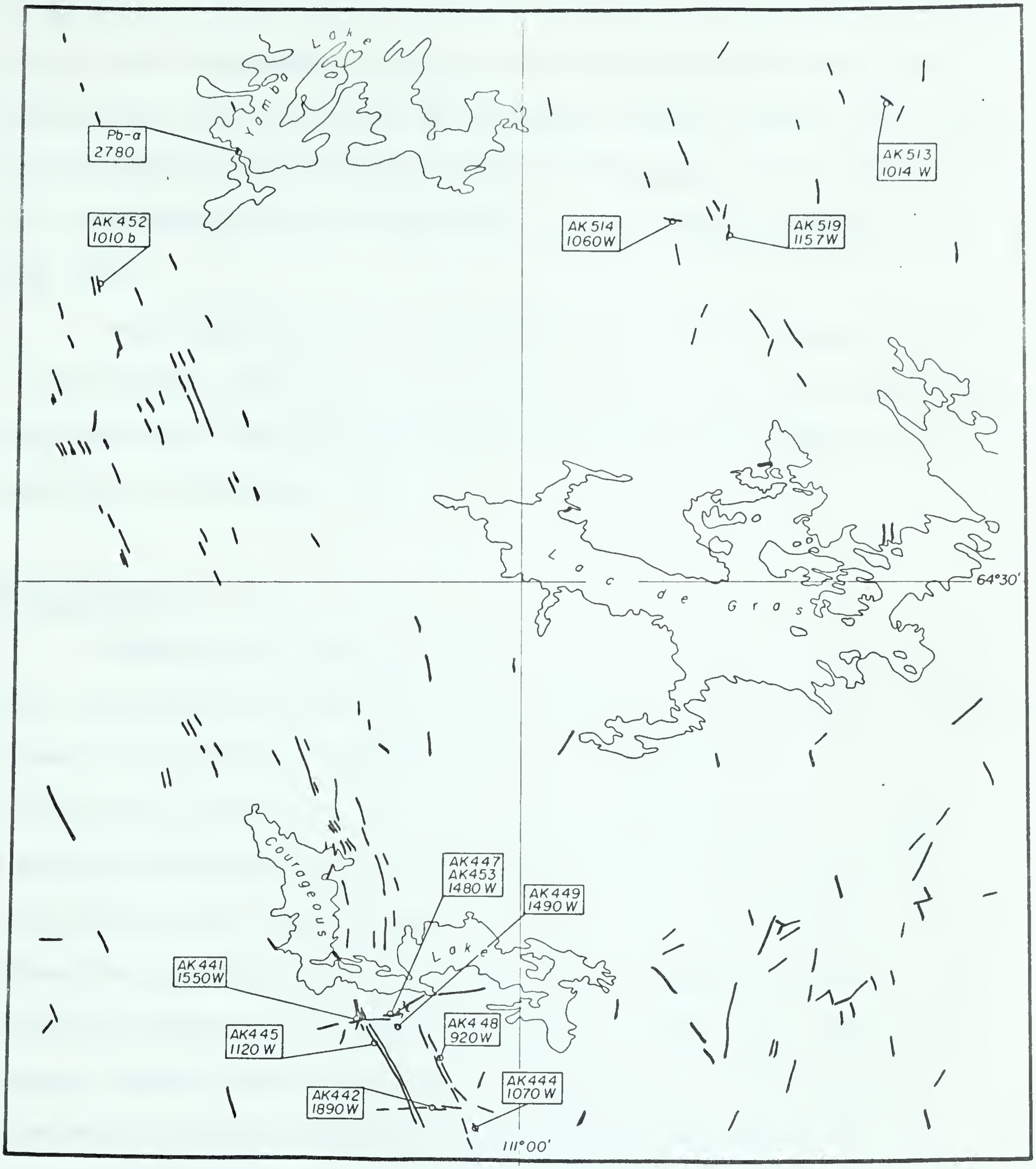
The Yellowknife group has been intruded and thermally metamorphosed to hornblende schists, quartz-mica schists, or slates and phyllites, by several generations of granitic rocks. Lit-par-lit injection of granite into sediments resulted in a gneiss, itself cut by massive granite. The granite has been divided into two sorts - biotite granite (and biotite-hornblende-granodiorite) and muscovite-biotite granite, with associated pegmatites. This is similar to the granite situation in Yellowknife.

Vertical gabbro and diabase dykes intrude all these rocks. The dominant trend is N 5° - 10°W although dykes with a N 0° - 30°E trend are present, and a very persistent N 80°E dyke set crosses the southern portion of the map. These three sets have been mapped in the adjacent Aylmer Lake area to the east (Lord, 1954).

The dykes in the area vary in width up to three hundred feet, one hundred foot-wide dykes being common. They weather the characteristic red-brown, and show diabasic texture. They look exactly like the dykes of the Yellowknife - Prosperous Lake area, and are composed of equal amounts of basic feldspar and pyroxene. Again, the dykes tend to occupy gullies and intersections are rare. In the Matthews Lake area (Moore, 1956) a north striking dyke is cut by a northwest - striking dyke and the pair of these cut out of the N 70°E dykes. No large scale faults of the Yellowknife type have been found, but there is an abundance of smaller faults mapped at Matthews Lake. The rocks have been folded in much the same manner as in the Yellowknife - Prosperous Lake region.

Figure 1 shows the trends of the dyke swarms and indicates the sample locations. Radiometric dates obtained from each sample are given as well.

Dating of the dykes in this area by Burwash _et al_. (1963) established that



LAC de GRAS
(after Folinsbee)

SCALE IN MILES
0 8 16

Figure 1. Outline Map showing sample locations and radiometric dates from diabase dykes of three sets, Lac de Gras area.

the dykes were of different ages and that they could be classified as belonging to Set I, or Set II, as at Yellowknife, according to trend and age. Set IV is not apparent in this area, but an additional N 0° - 30°W set appears (hereafter called Set III). Dating by the Geological Survey (Fahrig and Wanless, 1963) suggests an age of 1315 m.y. for Set III, somewhat older than the 1000-1100 m.y. group of ages reported by Burwash et al. 1963.

A gneiss-derived monazite from esker sands on Yamba Lake gives a Pb - α age of 2780 m.y. (Folinsbee, 1955). Thus the dykes are seen to cut Archaean rocks, as at Yellowknife. Similar Archaean ages have been reported from adjacent map areas (Lowdon et al. 1963; Lowdon, 1961).

Point Lake Area

Point Lake on the Coppermine River is directly northwest of the Lac de Gras area, and was one of the earliest areas mapped, since it lies on Stockwell's circular reconnaissance route north along the Yellowknife River to Coppermine River, east to Thonokied Lake, and southerly back to the east arm of Great Slave Lake. In 1931, Stockwell and Kidd stated "ancient areas of sediments and volcanics are known to exist near Point Lake". Later, these were described as type rocks for the Point Lake-Wilson Island group (Stockwell, 1933), and once more the oldest succession is one of volcanics and sediments folded and intruded by granite. Fraser et al. (1960) mapped the area from Point Lake north and west to Coronation Gulf. The basal assemblage of volcanics is succeeded by greywacke, slate, phyllite, and conglomerate. The lavas and their metamorphic derivatives are in long belts up to two miles wide and bounded on the west by thirty miles of granite and on the east by a similar width of sediment. The intruding granitic rocks are further subdivided into massive granites and gneissic granites or migmatites. Northwest of Point Lake, Proterozoic sediments are found. On a regional scale, two major fault patterns appear, cutting both Archaean

and Proterozoic rocks: most strike N 40° - 50°E and a fewer number strike N 60°W.

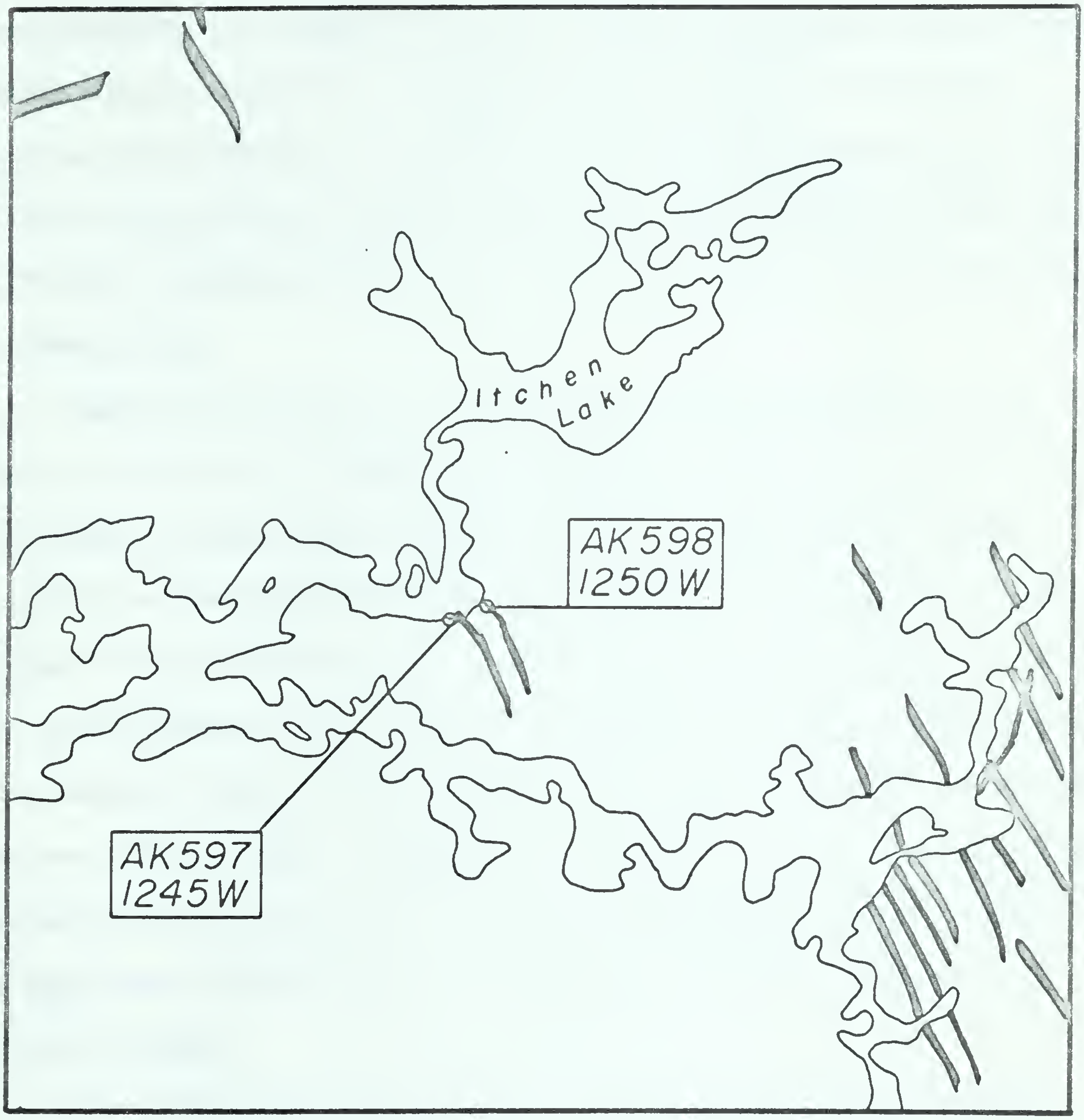
Diabase dykes and sills are again present, cutting the other Precambrian rocks. A few striking easterly and northeasterly may be found, but the majority trend about N 30°W. West of 115° west longitude the dyke swarm seems to thin out, but they are mapped to the east for some distance (Fraser, 1964). The northwest trending dyke swarm here is thought to be a continuation of the Lac de Gras - Aylmer Lake Set III.

Samples of the contacts of a N 20°W trending dyke were taken in the northeast arm of Point Lake, where the dyke cuts both volcanic and metasedimentary rocks. The sample locations are shown in Figure 2, with the two whole rock radiometric dates obtained from the dyke contacts.

Tree River - Coronation Gulf Area

The specific area under study was located at an unnamed lake, latitude 67° 37'N and longitude 111° 30' , about 8 miles south of Coronation Gulf, and 8 miles west of the Tree River. The Coppermine River area to the west has been well mapped. Jenney (1954) and Smith (1962) outline the history of exploration and the general geology. In addition, a geographic report of Bathurst Inlet has been made (Bird and Bird, 1961), but the general area between Point Lake and the coast remained unmapped until recently (Fraser, 1964). The smaller area described was being mapped by several mining companies as the result of a gold discovery to the north.

Greenstones and amphibolites derived from intermediate and acidic volcanics are the oldest rocks in the area; an irregular belt up to 8 miles wide and about 80 miles long extends from Grays Bay southward. The basic volcanics weather a light or dark green and may be folded, massive, pillowed, or vesicular. Associated tuffs and agglomerates are sometimes found. In the northern part of this belt, light-coloured rhyolites and dacites are common. All these rocks are intruded by granitic rocks. As at Lac de Gras and Point Lake, two major sorts, one massive and one gneissic or



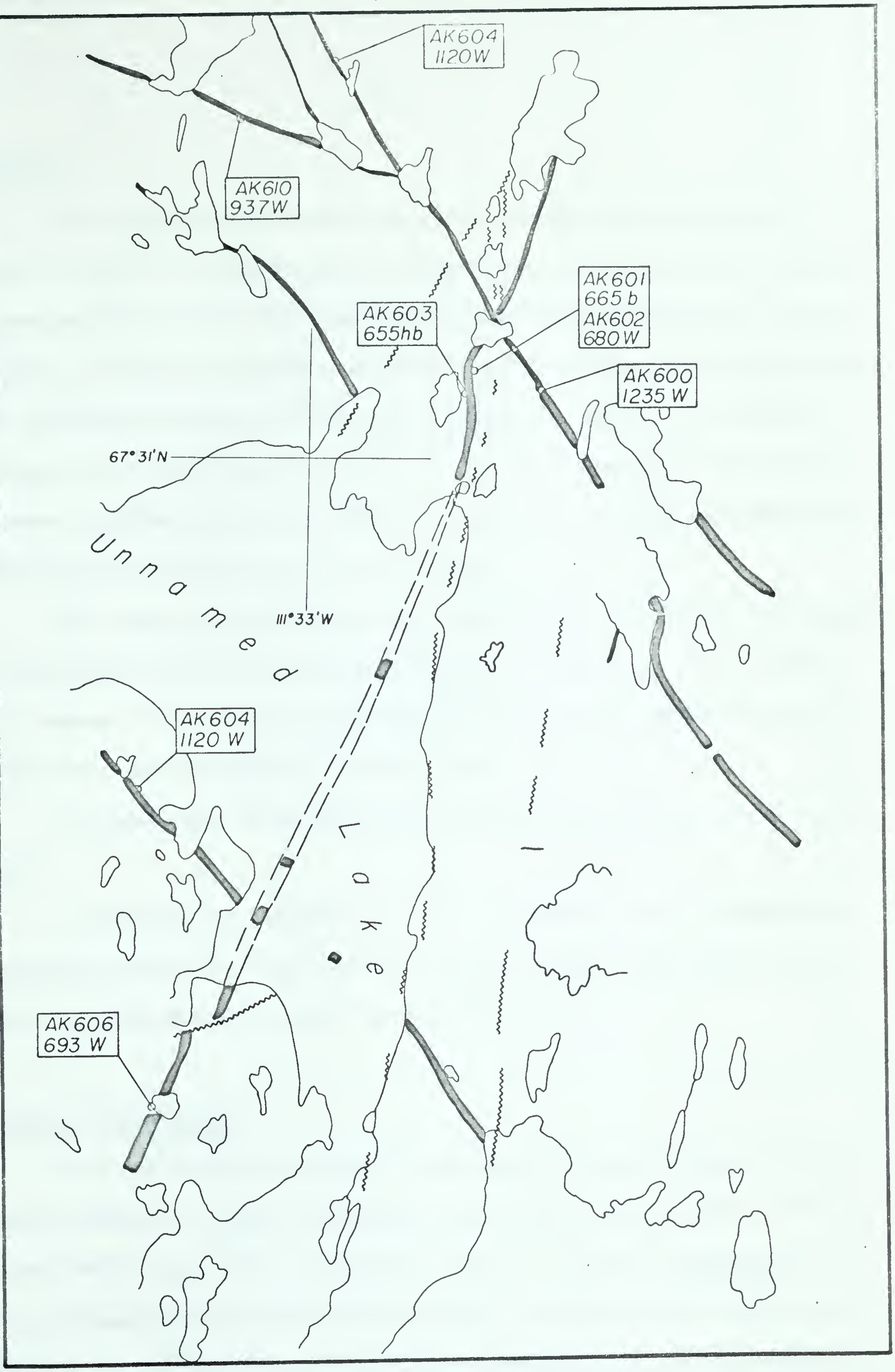
POINT LAKE
(after Fraser et al)

Figure 2. Outline Map showing sample locations and radiometric dates for a northwest - trending diabase dyke, Point Lake Area.

migmatitic, are to be found. The massive granites include granites and quartz-diorites; the gneisses and migmatites include lit-par-lit gneisses and appear to be derived from rocks of the Yellowknife series. In some areas, migmatites show evidence of alteration by younger granite. The exact relationships here are still in doubt, although two dates of 2100 m.y. and 1890 m.y. were obtained (Lowdon et al. 1963, p. 45) from a muscovite and a biotite separated from a quartz monzonite at 66° 58'N and 109° 54'W, indicating this area is in the Slave province (as defined by Stockwell, 1962, 1964a, 1964b).

Diabase dykes and sills cut these Precambrian rocks once again. In this northern part of the District of Mackenzie, especially near the coastal regions, the sills and sheets of diabase seem to be more plentiful than in more southern areas. Fraser (1964) considers these sheets or sills to be remnants of "once extensive undulating sheets". Where Paleozoic rocks overlie the Precambrian successions, the dykes do not cut the Paleozoic rocks. The dykes trend dominantly N 25°W, a few striking east and northeast, and can be found throughout the area, although they are fewer in number east of Bathurst Inlet. Altogether, this belt of northwest trending dykes seems to be about 200 miles wide, and at least 350 miles long. Major northwest trending faults pass through the Tree River area. The latest movement on the Bathurst Inlet Fault was pre-diabase.

Figure 3 shows the sample locations. The whole-rock dates (W) are from contact dyke samples. b and hb indicate that mineral separates, biotite or hornblende, were dated.



TREE RIVER AREA

(after PMSL)

SCALE IN FEET

0 1000 2000 3000 4000

Figure 3. Outline Map showing sample locations and radiometric dates, Tree River Area.

ONTARIO

The original purpose in obtaining samples of dykes from Ontario was to ascertain whether or not the northwest trending Keweenawan dykes in Ontario gave the same radiometric dates as the northwest trending dykes (Set III) of the Northwest Territories. To this end, samples of northwest trending dykes were taken near Sudbury, north of Sault Ste. Marie, and south of Fort William-Port Arthur. This suite was enlarged as the result of a contribution by Dr. Stewart A. Ferguson of the Ontario Department of Mines, who sent a number of samples from the Porcupine-Timmins area, of dykes trending northwest, north, and northeast.

The diabase dykes of Ontario are of several ages, and field evidence suggests that there may be more than one period of intrusion along a given trend. In some areas, presence of Huronian rocks that both cut and are cut by diabase dykes set limits on the time of intrusion of the different sets.

An index map of Ontario showing the general sample locations is given in Figure 4.

In the following discussions, the terms "Matachewan" and "Keweenawan" are used for convenience, since that is the way they appear on the regional maps, and no special significance is to be attached to the usage.

Porcupine - Timmins Area

As a result of gold discoveries in the Porcupine area, this region has been carefully studied by a number of geologists, most recently by Hurst (1936, 1939), Dunbar (1948), Moore (1953), and Ferguson (1959). In general, the geological setting is comparable to that of the Slave province: Archaean rocks, volcanics and sediments, are intruded by granitic type rocks, and these in turn by diabase dykes and sills. In the particular locations under study, no Huronian rocks are present, but where they do exist, two distinct groups of dykes are found, some of which are post-

INDEX MAP OF ONTARIO
SAMPLE LOCATIONS

Figure 4. Index Map of Ontario showing general sample locations.

Huronian. The dykes of the first type are generally quartz diabase and gabbro, and are mapped as "Matachewan". H. C. Cooke (1919) described these dykes in the Matachewan district. The later, younger dykes are thought to be olivine diabases, and have always been known as "Keweenawan" dykes. In the Gowganda area, Moore (1956) mapped both dyke types, as well as the Nipissing diabase, which is overlain by Cobalt sediments. The Nipissing diabase was once classed as Keweenawan but subsequent work (Lowdon, 1963; Van Schmus, 1963) suggests a probable age of intrusion of 2095-2170 m.y. The diabase dykes striking N 60° - 65°W in the Gowganda area are the youngest consolidated rocks.

Some confusion may result from the use of the term Keewatin, Timiskaming, Haileyburian, and Algoman. The oldest rocks are once more volcanics - rhyolites trachytes, dacites, andesites and basalts, together with associated pyroclastic and interbedded sedimentary rocks. These were assigned to the Keewatin series and called the Deloro and Tisdale groups in the Porcupine area. They are overlain conformably by a series of sediments (the Hoyle group) composed of conglomerates and greywacke which are unconformably succeeded by more sediments: slates, greywackes and conglomerates, with some trachytic volcanic rocks included. This last group of sedimentary rocks, above the unconformity, was known as the Timiskaming series. Basic and ultrabasic rocks (Haileyburian) intrude the volcanic-sedimentary series, and in turn are cut by (Algoman) granites, syenites and porphyries. Current usage avoids the terms Keewatin and Timiskaming, simply dividing the "older sediments" from the "younger sediments" with an unconformity, and denoting the entire sequence together with the acid, basic, and ultrabasic rocks intruding it, as Archaean.

At least two periods of extensive folding affected the Porcupine area, as well as several periods of faulting. The Destor-Porcupine fault, trending east-west, is thought to have originated during the Keewatin period, and is the major fault of the district. Several other faults parallel this major zone. A few north-south cross

folds offset the northeast faults: the Burrows-Benedict fault is the most important.

The map of the Porcupine - Timmins Area (in the pocket) shows the geology and sample locations in all the townships discussed - Keefer, Bristol, Tisdale and Taylor townships. Radiometric dates obtained from whole-rock samples are given on the map as well.

Keefer Township

The geology of the Keefer-Eldorado area was described by Harding and Berry (1939). The oldest rocks consist of massive and pillow lavas, usually basic andesites and basalts, together with tuffs and agglomerates. In other townships to the east, sedimentary rocks (conglomerate, greywacke, slate, and iron formation), are interbedded with the lava flows, and overlying sedimentary units can be found. Granites and associated pegmatites and porphyries intrude these volcanic rocks, and are gneissic in some places.

Diabase dykes of two sorts are mapped - north trending Matachewan quartz diabases, and northwest trending Keweenawan olivine diabases. The absence of the Cobalt series in the area prevents exact field correlation. In general, the Matachewan type dykes were found to range in width from a few feet to one hundred feet, to weather brown, and to be rather fine textured (as opposed to the coarse porphyritic appearance described in the Matachewan area). The Keweenawan dykes are classified on the basis of a lighter colour, coarser texture, and northwest trend.

The dyke sampled, of Matachewan type, trends north and outcrops cutting a granite. The granite has been assigned an age of 2390 m.y. (K-Ar) to 2510 m.y. (Rb-Sr) by Aldrich and Wetherill (1960).

Bristol Township

The geology of Bristol township was described in 1959 by Dr. S. A. Ferguson. The same early Precambrian volcanic - sedimentary sequence has been intruded by basic and acid rocks, and finally by diabase. Outcrops are scarce in this map area, and the contact between volcanic and sedimentary rocks was determined by an electromagnetic survey. Magnetometer traverses also located drift-covered diabase dykes.

Rhyolitic volcanics of the Keewatin series with associated tuff and agglomerate, outcrop in the northwest part of the area, and a band of intermediate volcanics transects the central map area from southwest to northeast. These are pillowed and amygdaloidal with small intercalated amounts of fragmental lavas and tuffs, and some irregular dioritic andesite. The lavas are uniform and difficult to correlate. In the southeast part of Bristol township, sediments of argillite and greywacke are found. Pyroxenite and hornblendite intrude all these rocks, as do monzonites and quartz-feldspar porphyries.

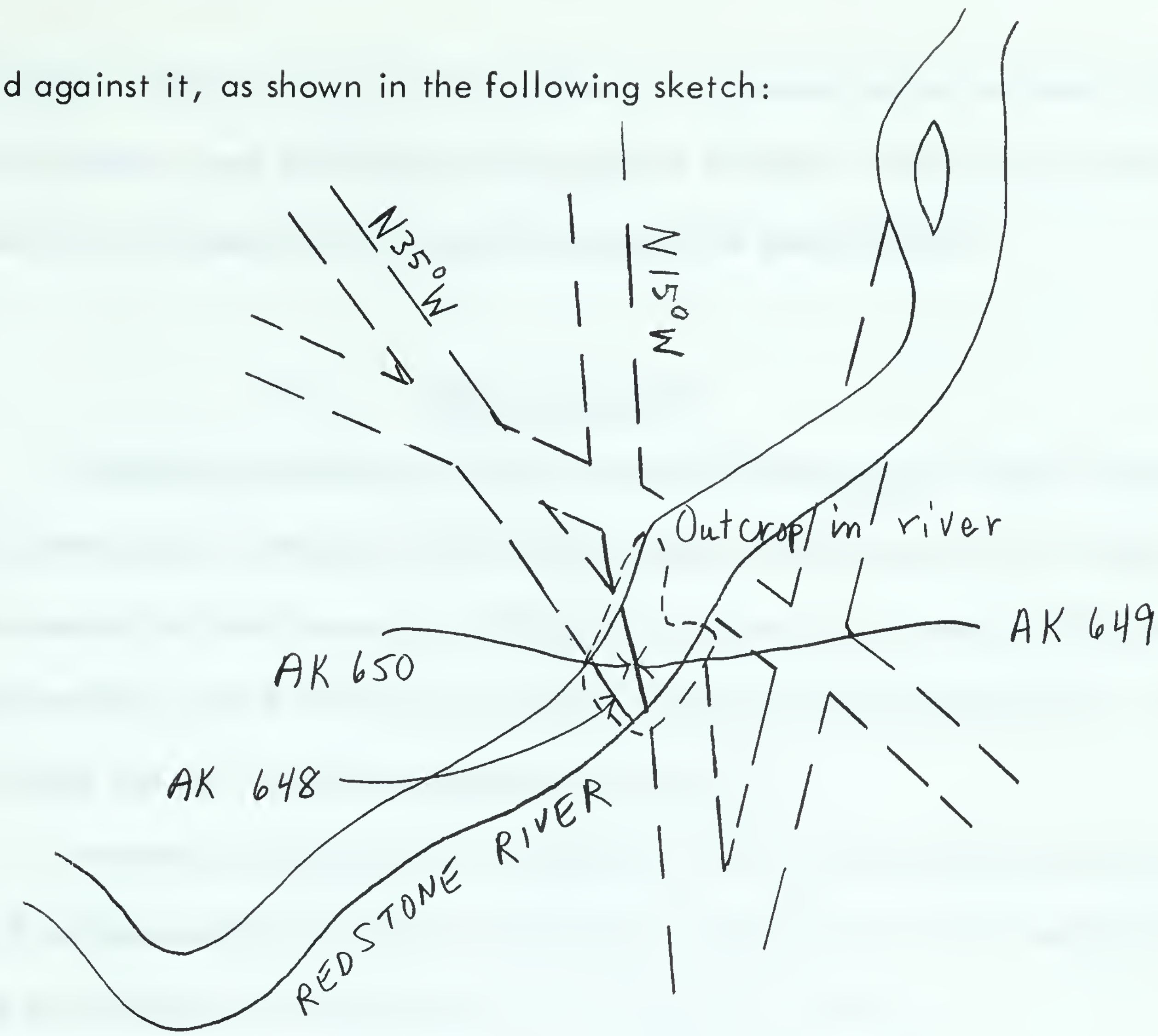
Structural relationships are obscure, but when the geological features of neighbouring townships are considered, two periods of folding and several of faulting, have affected the rocks.

The quartz diabase dykes in the area have been designated as Matachewan. The most prominent trend is N 5°W, but most dykes follow a sinuous course, dividing and rejoining, sometimes in an en-echelon pattern. The dykes vary in width, most of the larger dykes are less than 100 feet wide and persist along strike.

Petrographic study showed the dykes to be similar mineralogically, containing, augite, labradorite, quartz or micrographic intergrowth, and magnetite as the major accessory. This description is similar to that of Moore (1956) of the quartz diabase dykes of the Gowganda area.

The sample reported here was taken at an outcrop in the Tatachikapika (Redstone) River. A dyke striking N 15°W cuts a N 35°W striking dyke, and is

chilled against it, as shown in the following sketch:



Samples AK 648 and AK 650 are from the contact and the centre (respectively) of the oldest dyke. AK 649 was taken at the contact of the youngest dyke.

Tisdale Township

The geology of the mining properties in Tisdale township has most recently been described by Ferguson (1964), although a general map of the Porcupine area, including Tisdale township, appears in the same author's report on Bristol Township.

Again, a series of volcanic and sedimentary rocks are overlain with an angular unconformity by sediments (with minor volcanics) and intruded by peridotite and gabbro.

Folding has resulted in a broad synclinal structure with anticlinal margins occupying most of the area, and both the Destor-Porcupine and the Burrows-Benedict faults disrupt the region, together with numerous smaller faults.

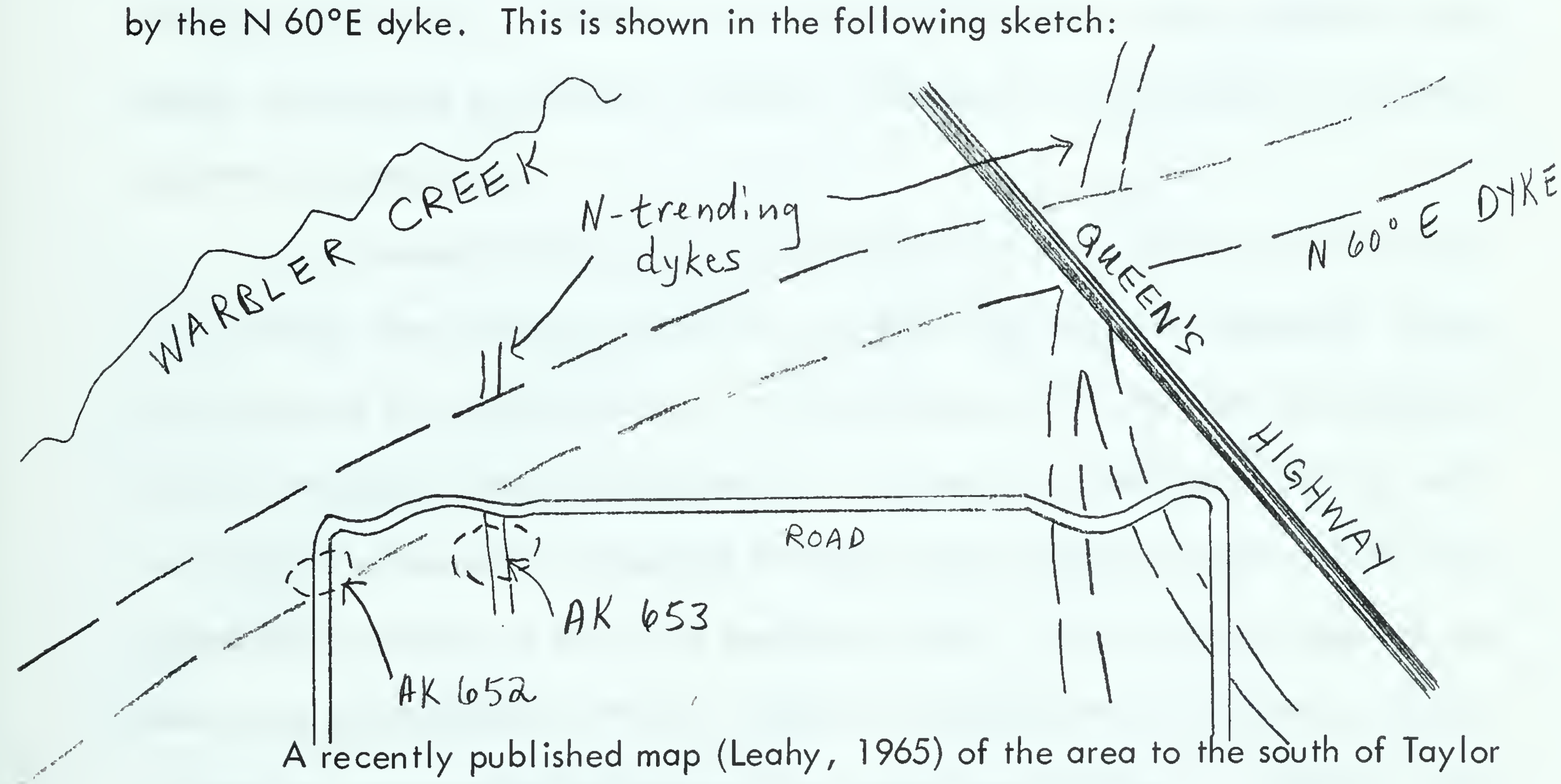
Diabase dykes of varying trends are found in the area: the dyke sampled was

as a N 30° - 40°W trending olivine diabase, as opposed to the northeast striking olivine diabases, and the north trending quartz diabases. The olivine diabases are referred to as Keweenawan, the quartz diabases as Matachewan.

Taylor Township

Preliminary mapping of Taylor township (Ginns et al. 1962) indicates that wide diabase dykes trending N 60°E (Keweenawan) and narrow north trending dykes (Matachewan) are both present, cutting basic volcanic rocks south of the Destor-Porcupine fault, and Keewatin and undifferentiated sediments north of it. The large dykes can be traced by magnetometer survey.

Two east trending dykes are observed in this township and one sample was taken from the southernmost dyke, as well as another from a north trending dyke cut by the N 60°E dyke. This is shown in the following sketch:



A recently published map (Leahy, 1965) of the area to the south of Taylor Township shows this same dyke intruding intermediate to basic volcanic rocks that are massive, pillowed or porphyritic, and undifferentiated acid to intermediate volcanics. At one place it cuts a feldspar porphyry. In the southern part of Currie township, a parallel dyke is shown cutting several north trending dykes.

Sudbury Area

The geology of this area is so complex that the origins, ages and structural relationships of nearly all the rock units are still being debated. A comprehensive review of the literature published prior to 1956 is given by Thomson (1957) and, more recently, by Hawley (1962). These authors discuss the general geology of the area.

Several diabase dykes are found, intruding the formations inside the nickel irruptive as well as the pre-Huronian rocks to the south (Thomson, 1962). The brown weathering olivine diabases were described by Cooke (1946), who distinguished them from "trap" dykes - fine-grained, uralitic diabases, striking east-west, which cut the norite, but are cut by the late olivine diabase dykes. These later dykes weather rapidly into walled gullies, vary in width from fifty to more than one hundred feet and for the most part strike northwest. With respect to composition, they are composed of 60-70% labradorite, 15-20% augite, and 10-15% olivine, with magnetite, brown biotite, and apatite as accessory minerals. The texture is ophitic and the minerals are fresh in appearance.

The geology of the area around the city of Sudbury is shown in Figure 5. The particular dyke chosen for sampling (AK 616, Figure 5) was mapped by Thomson (1957) north of the city of Sudbury cutting the Copper Cliff rhyolite and probably the volcanic members of the McKim formation. However, in hand specimens the wall rock (AK 617, Figure 5) northeast of the dyke did not satisfy any description of the Copper Cliff rhyolite, or any of its associated rocks. In thin section, the rock was found to be an amphibolite (Plate 2, Figure 4) slightly altered in places to chlorite. A potassium argon whole-rock date of this sample gave 2420 m.y. Dating by others in the Sudbury area has established that the Copper Cliff rhyolite is the oldest igneous rock (2200 m.y.) and that the nickel irruptive and the intrabasinal slates are older than 1600 m.y. (Fairbairn et al. 1960; Faure et al. 1962).

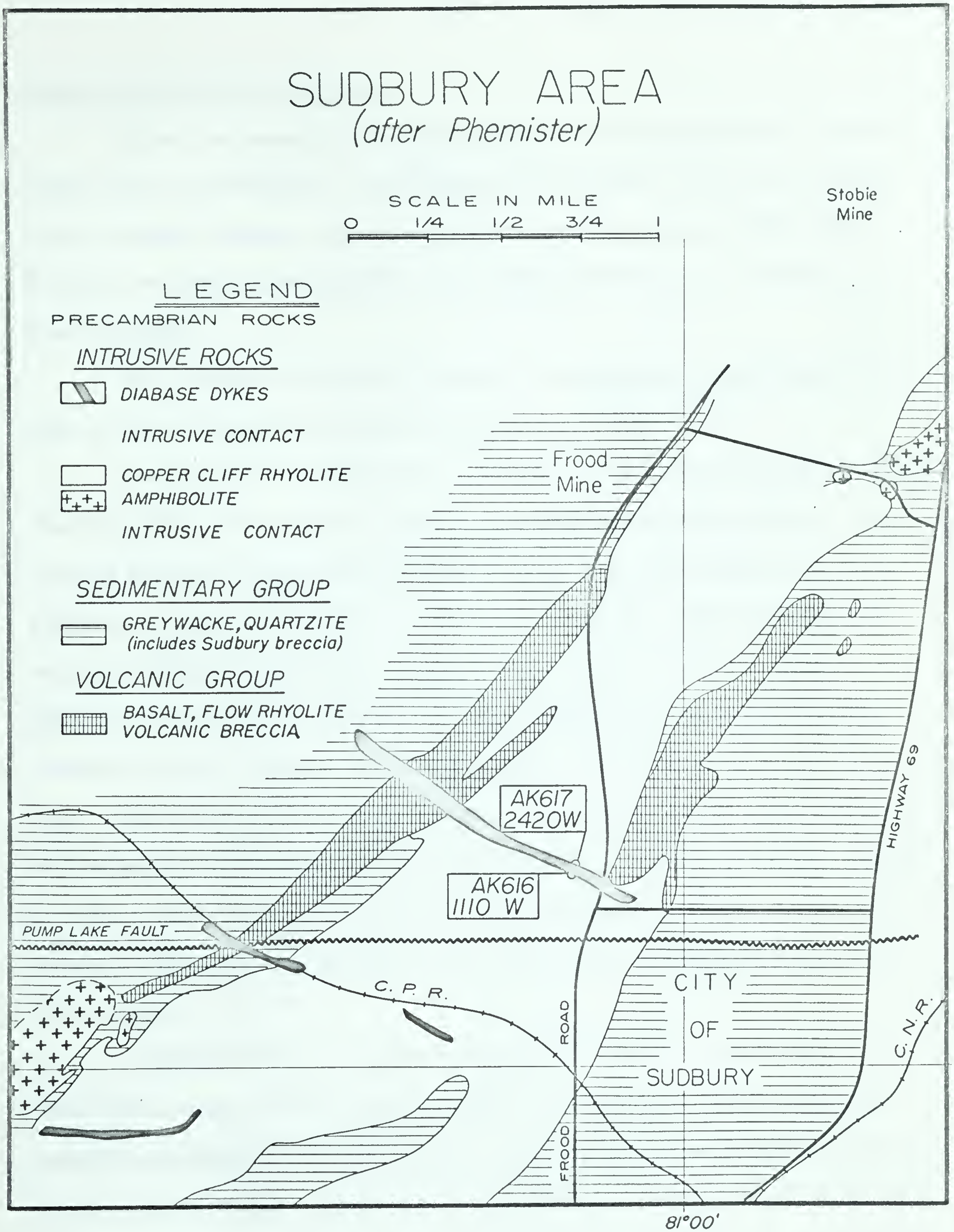


Figure 5. Geological Map of the Sudbury Area, showing sample locations and radiometric dates.

Chippewa Falls (Batchawana) Area

Where the Harmony River, locally known as the Chippewa River, flows into Harmony Bay on Lake Superior, the Chippewa Falls are found. The river must flow over a northwest trending, vertical, sixty-five foot thick, resistant diabase dyke. This dyke was sampled (see Figure 6), and a whole-rock radiometric date obtained from one sample.

The Chippewa Falls may be precisely located along the Trans-Canada highway, where the Chippewa Falls Park is located (Pye, 1962).

The geology of the Batchawana area (Figure 6) was reported by Moore (1927). The oldest rocks of the area are a series of metamorphosed sediments and lava flows. The acid and basic flows, slate, greywacke, arkose, and iron formation, are cut by a diabase and gabbro rock which, in turn, in cut by granite. Dykes of both olivine and quartz diabase cut the older, granite intruded rocks, and where no granite is present, it is impossible to distinguish the early diabase and gabbro rock from the post-granite quartz diabases. The olivine diabase is the latest intrusive rock in the area. Some Keweenawan sediments are present, and it is possible to place the dykes as Keweenawan: near the Chippewa Falls, the granite intruded by the dyke is capped by a thin erosional remnant of middle Keweenawan lava (Pye, 1962). Moore (1927) included a photograph of the dyke contact in his report, considering the dyke to be Keweenawan.

McConnel (1927) outlined the geology of the Sault Ste. Marie area to the south, where rocks of Huronian age are present. He found both pre-Huronian and post-Huronian diabases. No Keweenawan rocks were recognized in this region, but the latest dykes, of quartz diabase and olivine diabase, were considered Keweenawan.

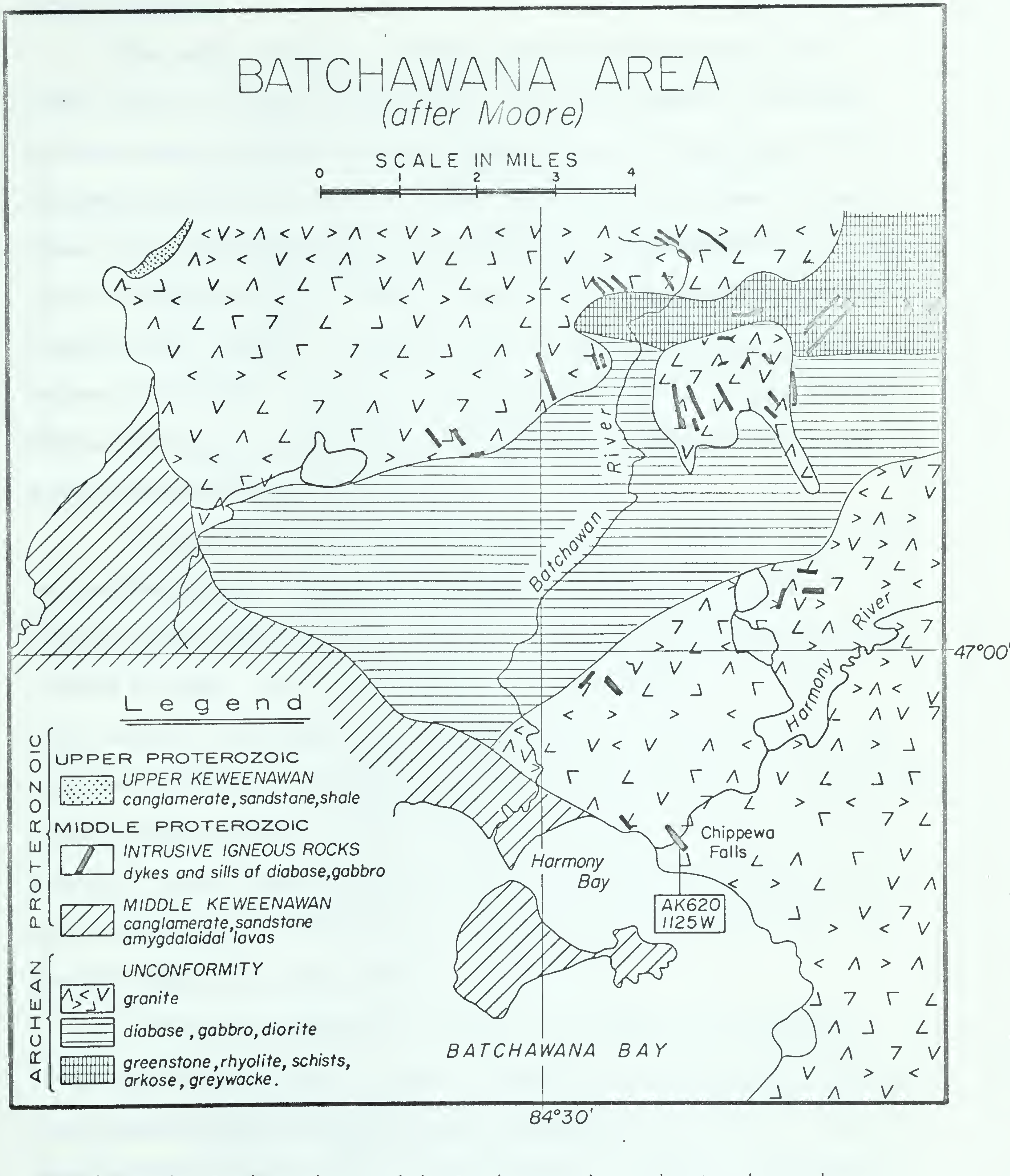


Figure 6. Geological Map of the Batchawana Area, showing the northwest trending diabase dyke which was sampled and dated.

Pigeon River Area

The samples collected in this area were taken from dykes and sills of diabase that outcrop along the Pigeon River, which flows along the international boundary between Canada and the United States (Figure 7). Tanton's map (1936) of the area shows two series of falls and rapid along the river: The Horne Falls and the Pigeon Falls. The rapids midway between have been renamed Middle Falls. A more recent map (Pye and Fenwick, 1963) differentiates the dykes and sills that intrude the Rove formation. Diabases were obtained from northwest and northeast trending dykes, and one sill, but work was done only on the sill and a northwest trending dyke from Middle Falls (Figure 7). The resistant dyke forms the lip of Middle Falls, and has been photographed by Pye (1962).

Tanton (1931) divided the Precambrian rocks into two main divisions, Early and Late Precambrian. The Early Precambrian included the schist complex, of highly altered volcanic rocks and a variety of schists, and the granites and granite gneisses intrusive into them. The Late Precambrian rocks unconformably overlying the earlier sequence were called the Kaministikwan group. The Animikie series, made up of three formations, the Kakabeka, the Gun Flint, and the Rove, was succeeded by the Osler series and finally the Sibley Series, and all these early rocks were cut by intrusives. Tanton thought the three series were separated disconformably, but later work has shown that an unconformity exists between the Animikie (Huronian), and the Osler-Sibley group (Keweenawan).

Tanton gives a detailed description of the distribution and lithological character of the dykes: they are typical. They range in width from a few inches to a few hundreds of feet, have been traced for long distances, dip vertically, have well developed jointing and are closely related to the sills. Some sills are extensions of dykes, others are cut by dykes. Chilled margins of both dykes and sills are common; away from the contact zone, the dykes are medium-grained, show an ophitic texture,

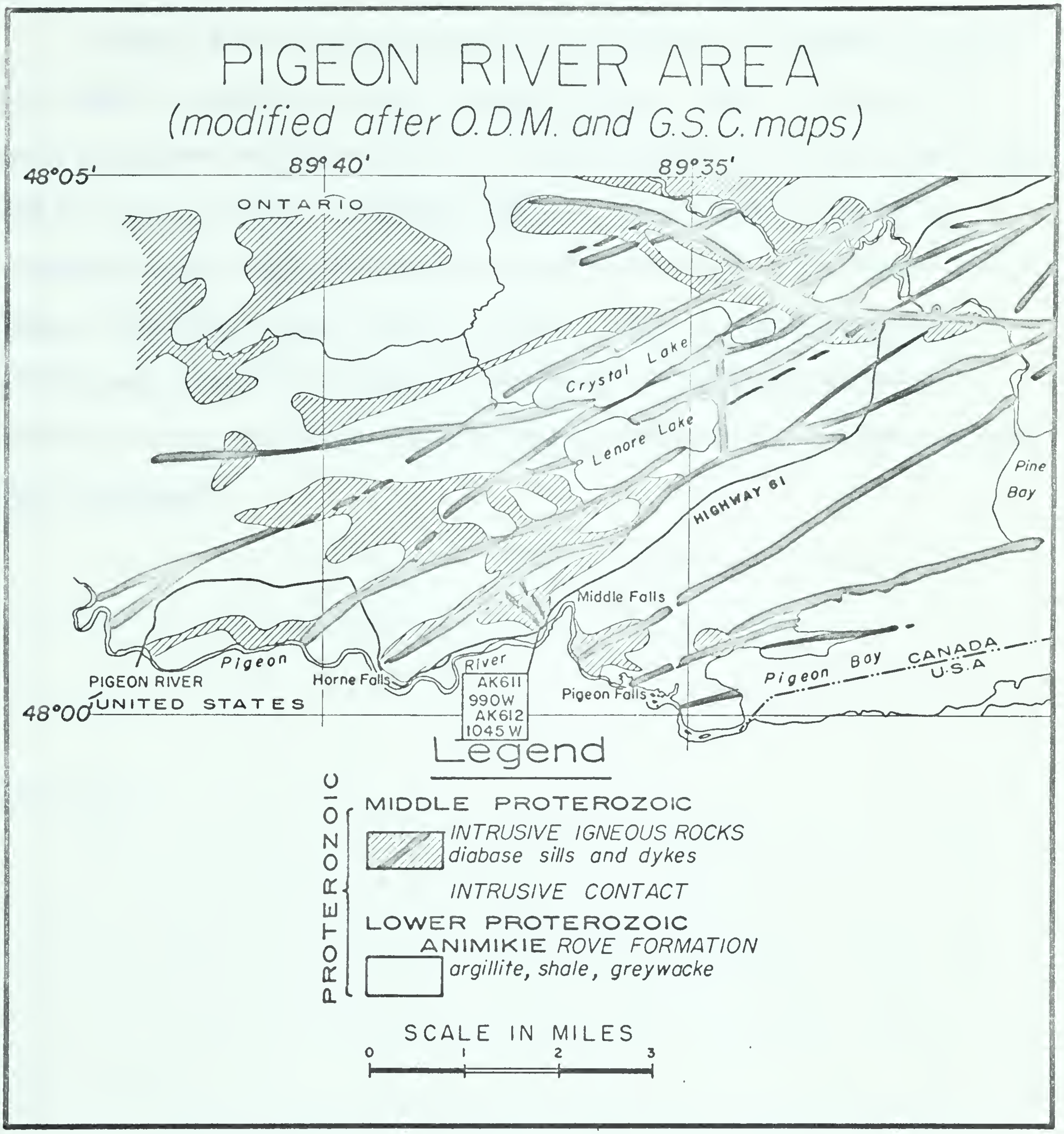


Figure 7. Geological Map of the Pigeon River Area, showing the sample locations and radiometric dates for a sill (AK 612) cut by a northwest-trending diabase dyke (AK 611).

and consist essentially of pyroxene (augite) and lathed plagioclase (labradorite or oligoclase). Apatite, olivine, and iron ore are the accessory minerals.

A study of Precambrian geology and geochronology in Minnesota by Goldich et al. (1961) included that of adjacent areas in Ontario. Important and pertinent results of this work included recognition of a Post-Animikie event, the Penokean, about 1700 m.y. ago, as well as the Algoman 2500 m.y. orogeny and the still earlier Laurentian events. The Duluth complex and related intrusives, reflecting the Grenville orogeny, were dated at about 1100 m.y. Since the Duluth complex intrudes the Animike rocks, about the same age was expected for the dykes and sills nearby in Canada, since they too intrude Animikie strata (as well as the Osler-Sibley succession when it is present).

COMPOSITION

"The composition of an element in a rock is unknowable".

D. M. Shaw.

For the purpose of radiometric dating, it is essential that the potassium content of the samples be known accurately. Having determined the amount of potassium in more than eighty samples, none of which gave the same result for the same sample, this analyst agrees with Shaw.

The sodium and silica contents of the same samples were determined with much less trouble (and accuracy), using a single method for each constituent.

ALKALI CONTENT

Consideration of the potassium results dominates the following paragraphs; the sodium content is discussed later in relation to the alkali-silica ratios of these rocks.

Previous Work

Since such difficulty was experienced in reaching a conclusion concerning the most accurate potassium content of the whole rock samples, it is worthwhile to examine the analytical results obtained by a few other investigators. In most cases, several recent determinations have been made using the same method, and good precision is reported.

For example, McDougall (1964) determined the potassium content of eight whole rock samples of Hawaiian lava flows by a method described by Cooper (1963). The replicate potassium analyses agree within one percent, and the range in value is from 0.844% K_2O to 3.549% K_2O. Krueger (1964) determined potassium by a flame photometric method as well for two samples of "Mohole" basalt: values of 0.210, 0.219, 0.219, 0.206 and 0.226 percent K_2O were obtained for one sample, and values

of 0.145, 0.155 and 0.164 percent K_2O for the other. This is better precision than that obtained by this analyst.

With respect to x-ray - fluorescence potassium determinations, a standard deviation can be assigned to values obtained, using a chemical or rock standard such as W-1. The standard deviation of the results given here is $\pm$ 2.0 percent; Lessing et al. (1963) assigned a standard deviation of 2.8 percent to their determinations of potassium in Hawaiian lavas. That the matrix of the potassium seems to have a substantial effect, especially at low levels, is suggested in personal communication with W. F. Fahrig of the Geological Survey of Canada, Ottawa. Andrew Turek, presently at the Department of Geophysics of the Australian National University, Canberra, advises that B. Chappell of the Geology Department at Canberra "does accurate K_2O determinations by x-ray - fluorescence, but has to correct for all the other elements present using a 1620 computer".

The many analyses published on W-1 show what is possible when a sample is analysed by different methods in different laboratories by careful analysts. A few comparative analyses of other basic rocks are available. McDougall (1963a) carried out potassium determinations of whole rock samples and mineral separates from Antarctic and South African dolerites. Duplicate flame photometric analyses were made and isotope dilution checks on eight samples gave agreement usually better than $\pm$ 2.5 percent, although discrepancies of up to 5.0 percent occurred. Heier, et al. (1964) determined the potassium contents of Hawaiian lavas using x-ray spectrometry, atomic absorption, and flame photometry. In general, the x-ray spectrometric results were eight percent lower than the flame photometric results, which gave the accepted value for potassium (0.54 percent) by Cooper's method. Lovering and Richards (1964), however, state that Cooper's method is "not generally reliable" at low levels of potassium abundance (0.1%) and used the isotope dilution method as a check, together with another flame photometric method (Easton and

Lovering, 1964). For samples with very small amounts of potassium (<0.15% K_2O), errors ranged up to 100 percent, but for higher values (up to 0.5 percent), agreement is better.

A recent report by G. R. Lachance (1965) concerns the x-ray spectrographic determination of potassium in micas. Although the percent potassium was much higher than that of diabase, Lachance's results show the same type of variation as the x-ray results discussed below, which were obtained by the writer.

<u>Present Work</u>

It was hoped that three independent methods would produce the same result for the same sample. This was seldom the case, although careful analytical procedure was followed in all cases and for all methods. Standards, when necessary, were prepared accurately. When it was obvious that something was amiss during a determination, that sample was discarded and the determination was repeated.

The three methods used for potassium determination are described in detail in Appendix B. Briefly, they include:

1. a gravimetric method involving leaching of potassium and precipitation with sodium tetraphenol borate,
2. a flame photometric method following leaching of potassium, and
3. an x-ray - fluorescence method using the powdered whole rock.

Splits of the same prepared sample were used for each separate method. The sodium content of the samples was measured by the flame photometric method only.

From all the results available, a plot of percent K_2O by tetraphenol boron precipitation versus percent K_2O by both flame photometric and x-ray - fluorescence methods was made (Figures 8, 8a). Since two runs (separated by a time interval of one month) were made by x-ray fluorescence, a range of values plot is obtained, and used, since it is more informative than a single point representing the average

of the two determinations.

If the three methods had given the same percent K_2O for each sample, then a line drawn through the points would have a zero intercept and a slope of unity. However, from Figures 8, 8a, it is obvious that the flame photometric method and the x-ray - fluorescence method gave similar values, and that both were lower than the percent K_2O obtained from the gravimetric (precipitation) method. The x-ray - fluorescence results are consistently lower than the gravimetric results; the flame photometric results are lower in the 0 - 1.0 percent K_2O - content - range only. In any case, since comparatively few samples had a K_2O content from 1.5 to 3.0 percent, these lines are less meaningful in this range. However, in lower ranges the average slope of the two lines is close to 1 (0.96) and the average intercept is 0.07. This conclusion was reached by both visual estimation of "best fit" lines and by the statistical "least squares" method of the fitting of a line to a set of experimental data.

Therefore, in choosing the best percent K_2O value the tendency was to reduce the gravimetric result and then to take the average of the three values. The following factors were considered:

1. Precipitation values are best for greater than 0.5 percent K_2O. The weighing error in the balance is $\pm$ 0.1 mg. It is therefore necessary to weight at least 10 mg. of precipitate for this error to be less than one percent. For a one gram sample, this represents about 0.15 percent K_2O. Since it was not convenient to handle samples of more than one gram, this method is not accurate for samples with less than 0.15 percent K_2O.
2. Precipitation values are reproducible: two determinations on AK 584 gave 2.021 and 2.000 percent K_2O and on W-1, 0.680 and 0.677 percent K_2O.
3. Precipitation values are high for W-1, the Centerville diabase, which

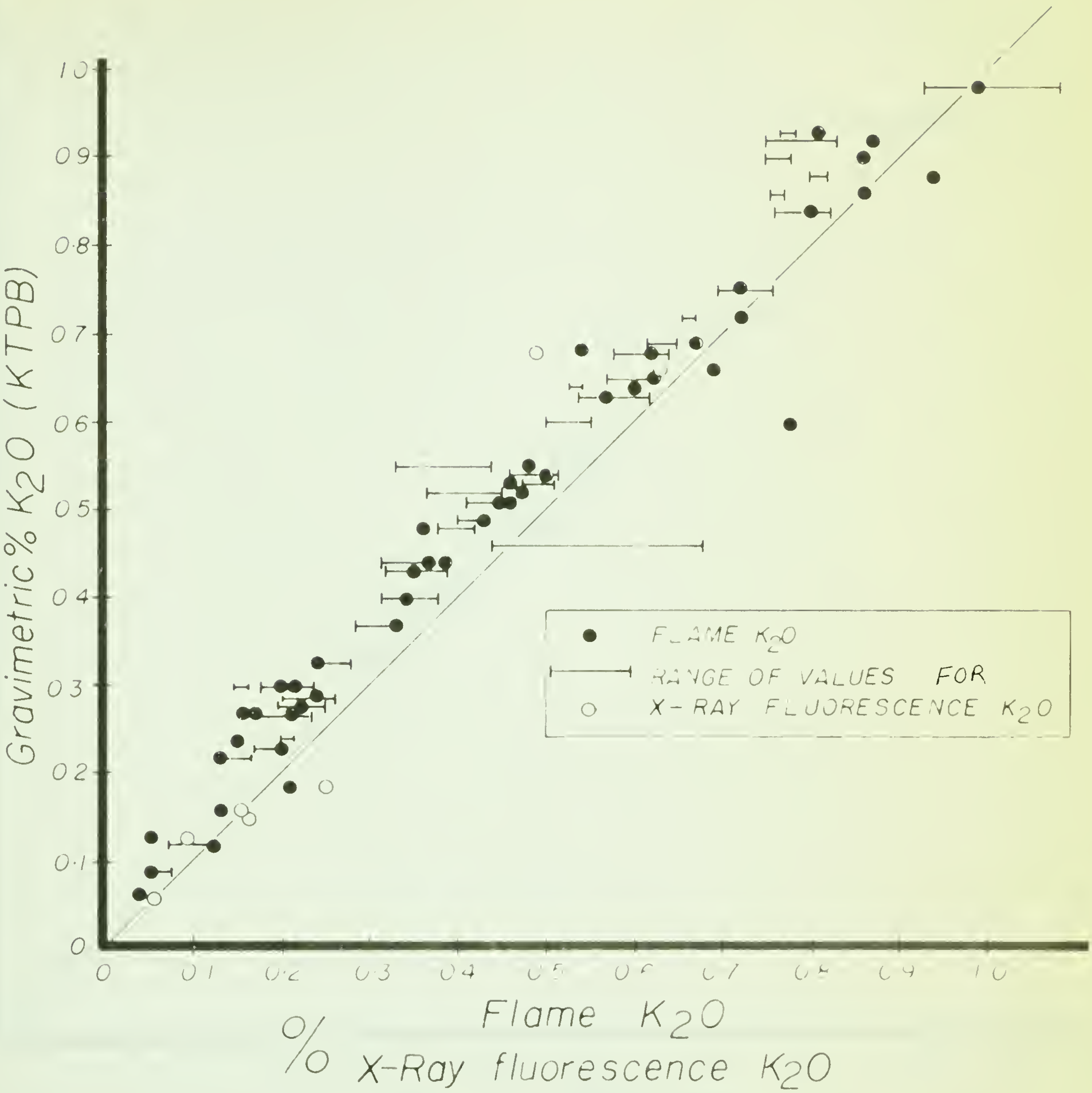


Figure 8. Relationship of results for the three different methods of potassium determination, in the range 0.0 - 1.0 percent K_2O.

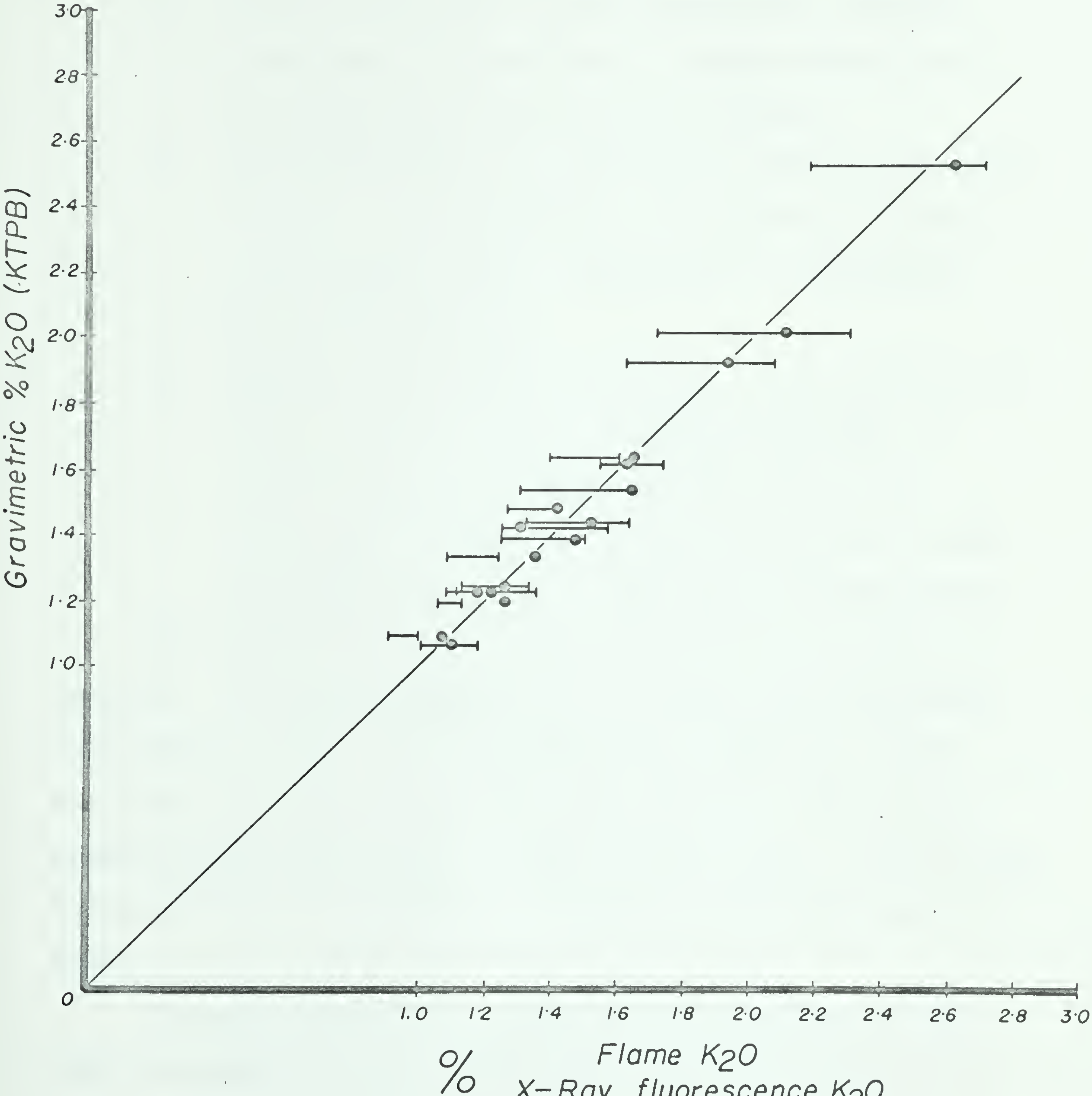


Figure 8a. Relationship of results for the three different methods of potassium determination, in the range 1.0 - 3.0 percent K_2O.

was assigned a value of 0.62 percent K_2O by Goldich and Oslund (1956) and 0.64 percent K_2O by Fleischer and Stevens (1962).

4. Flame photometric values may tend to be lower than precipitation methods because of the modification in method, although values for W-1 of 0.624 and 0.640 percent K_2O were obtained.

5. X-ray - fluorescence values were determined using W-1 as a standard. In this way, some compensation for matrix effects over the limited range of diabase composition was achieved. W-1 was assigned a value of 0.62 percent K_2O.

6. At greater than 1.0 percent K_2O, there is too large a variation in the x-ray - fluorescence values, but for samples with less than 1.0 percent K_2O, results were reproducible within $\pm$ 2.0 percent. Results were still reproducible within this range when new briquettes were prepared from the original sample and the runs were repeated.

The results of all potassium analyses on whole rock samples are given in Appendix C. The samples are grouped according to area and trend (when possible) of the individual intrusions. Some of the samples used, marked with an asterisk * have (1) been discussed in a previous publication (Burwash et al. 1963) or (2) been assigned a potassium-argon date by a person other than the author. In these instances, the bracketed figures, not used in future calculations, are those determined by this analyst.

The results of these potassium analyses are shown graphically in Figure 9, where the 86 samples give a mean value of 0.70 percent K_2O. Samples from both dykes and sills are included. If the potassium content of samples taken only from chilled margins of the intrusives is considered, 51 samples give a mean value of 0.66 percent K_2O. For the seventy-four dyke samples, the average Na_2O content is 2.36 percent.

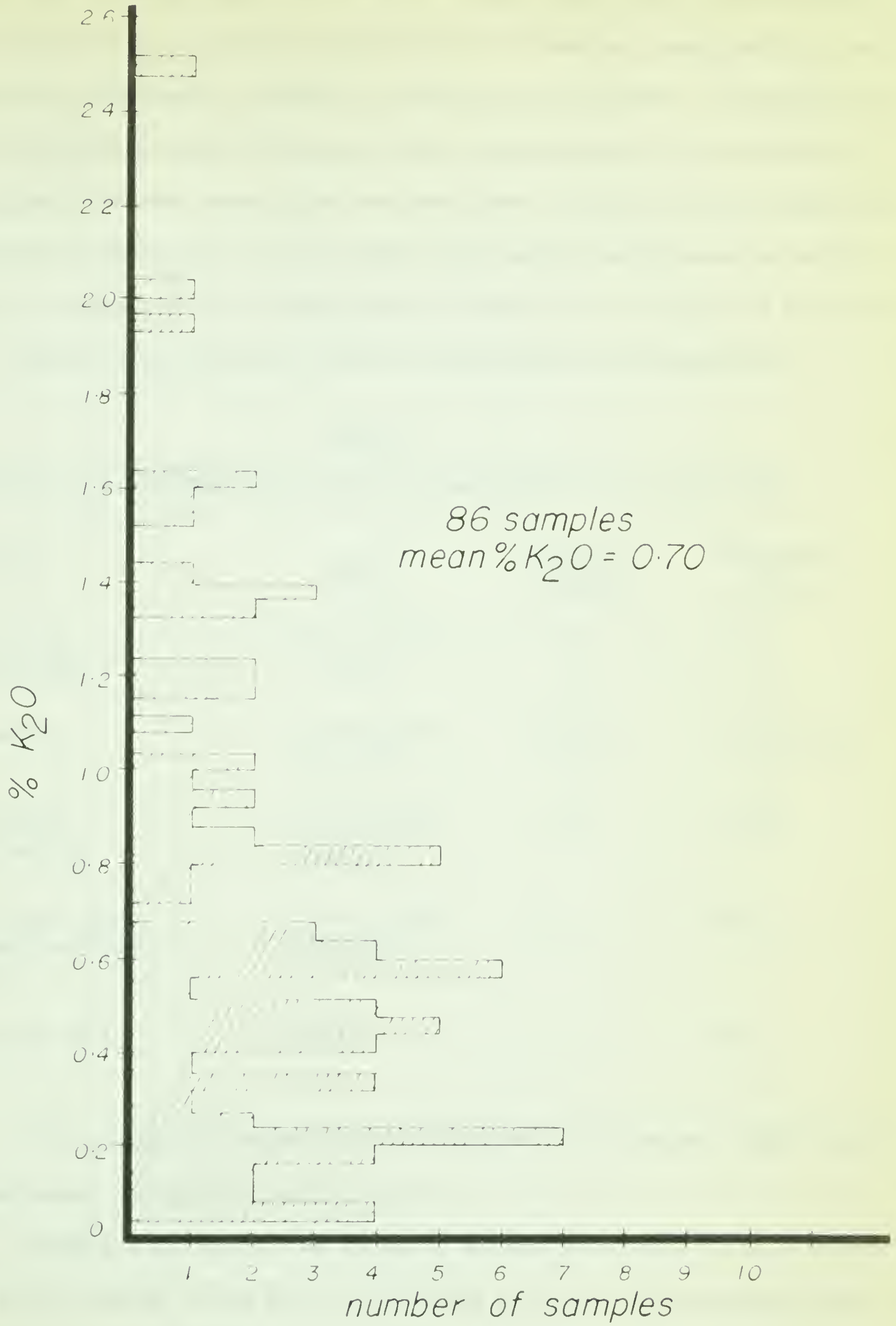


Figure 9. K_2O content of basic dykes and sills

One of the purposes of this thesis was to see if dykes could be assigned to a swarm or set of a given age with a particular trend. Therefore, these results are now treated more individually, in Table 2. The sills are not included. It is realized that the chilled contact zones of dykes may be more representative of the composition of the originally intruded material than the centre zones. However, of the samples from the District of Mackenzie, 35 were chilled margin samples and 29 were centre dyke samples. Consideration of all these samples will best give an indication of the nature of the original intrusive material, since the whole dyke is thus represented.

TABLE 2

AVERAGE K_2O CONTENT FOR DYKES IN THE DISTRICT OF MACKENZIE

Area	Trend	Number of samples		Average % K_2O	
Yellowknife, Lac de Gras	N 70° - 80°E (Set I)	24	46	0.63	0.56
Yellowknife	N 30° - 60°W (Set IV)	13		0.33	
Yellowknife, Lac de Gras	N 0° - 30°E (Set II)	9		0.70	
Lac de Gras, Point Lake, Coronation Gulf	N 0° - 30°W (Set III)	15		0.91	
Coronation Gulf	N 30°E	3		0.41	

The average K_2O content of these 64 samples is 0.63 percent, slightly lower than the overall average expressed in Figure 9.

Table 2 is arranged so that the age of intrusion decreases from top to bottom: dykes of Set I and Set IV and Set II are the oldest and Set III and the northeast trending dyke at Coronation Gulf are the youngest.

If the dykes of Set I, Set IV, and Set II are considered together, 46 samples have a mean value of 0.56 percent K_2O. This is lower than the mean of 0.63 percent, and much lower than the average value of 0.91 percent K_2O in the dykes of Set III. Thus the results presented here suggest that the older Precambrian dykes have a lower potassium content than the younger dykes. This idea was pointed out by Burwash et al. (1963). Data from the N 30°E dyke near Coronation Gulf would not support this idea, but insufficient information prohibits comment.

The small number of samples from Ontario makes comparisons of averages from different sets difficult. But if the dykes are considered to belong to only two groups, "Matachewan" or "Keweenawan", the older Matachewan dykes seem to have a lower potassium content than the younger Keweenawan dykes. This is shown in Table 3.

TABLE 3

AVERAGE K_2O CONTENT FOR DYKES IN ONTARIO

Area	Trend	Number of samples	Average % K_2O
Porcupine-Timmins	"Matachewan" N 10°W to N 10°E	5	0.77
Porcupine-Timmins	"Keweenawan" N 10° - 40°W	8) 10	1.13) 0.94
Sudbury, Chippewa Falls, Pigeon River	N 50° - 80°E	2)	0.18)

Two other circumstances are noteable; (1) The older "Matachewan" dykes have an average percent K_2O comparable to that of Set II of the district of Mackenzie (0.70 percent K_2O) and, (2) the younger "Keweenawan" dykes have a mean value of 0.94 percent K_2O, very close to the 0.91 percent average K_2O content of the N 0° - 30°W set of the district of Mackenzie (Set III).

Green and Poldervaart (1955) remark that "there is no consistent variation in the composition of basalt magma with time". They present tables showing world

basalt compositional averages for Cenozoic, Mesozoic, Paleozoic, and Precambrian rocks. The analyses were recalculated on a water-free basis, but this does not effect the general situation: Their average K_2O for Precambrian basalts is 0.6 percent; for Paleozoic basalts, 1.3 percent; for Mesozoic and Cenozoic basalts, 1.0 percent. The Precambrian basaltic rocks thus seem to have had a lower potassium content than more recent basalts. From this study, there is an indication of a systematic increase in potassium content from Archaean to Late Proterozoic time.

The average potassium content of the dykes and sills of this study may be compared to that obtained by others in Canada and remoter Shield areas. Burwash *et al*. (1963) obtained a mean value of 0.88 percent K_2O for forty-five samples of dykes from the District of Mackenzie. Fairbairn *et al*. (1953) measured the minor element content of Ontario diabases and the Duluth gabbro. Calibrating spectrochemical results in terms of W-1 having 0.69 percent K_2O, they obtained an average value of 0.94 percent K_2O for 38 specimens. A year earlier Ahrens *et al*. obtained an average value of 0.94 percent K_2O for Ontario diabases. A worldwide average potassium content of quartz diabase dykes and sills is given by Turner and Verhoogen (1960) as 0.83 percent K_2O. Prinz (1964) found the average K_2O content in late Precambrian dykes in the Beartooth Mountains (Western United States) to be 1.1 percent and compares this to 0.6 percent K_2O (calculated water free) for the Bushveld complex of Africa.

The average potassium content of the Canadian intrusives compares well with the potassium content of younger basaltic rocks such as the Hawaiian lavas (Macdonald and Katsura, 1962, 1964), the Columbia River Basalts (Waters, 1962) and the Karroo Dolerites (Walker and Poldervaart, 1949) among others.

The potassium content of these basic intrusives indicates that they are typical in comparison with other basic intrusives, and that there may be some justification in grouping them according to area, trend and age.

ALKALI - SILICA PROPORTION

Kennedy (1933) recognized two dominant types of basaltic rock, the tholeiites and the alkali olivine basalts, and it is possible to classify the basic intrusive bodies of the Precambrian Shield as either tholeiitic or alkalic (or both) in nature.

In 1785 James Hutton is reported to have said that the present is the key to the past. Since both basalt types are present in the volcanic rocks of Hawaii, it was decided to use them as a primary basis of comparison for the basic rocks of the Precambrian Shield. Extensive studies have been made by many authors, among them H. T. Stearns, C. E. Tilley, H. A. Powers, Hisashi Kuno, G. A. Macdonald and T. Katsura. A historical discussion of the development of ideas about the basalt types in Hawaii and their relationships to each other is given in a recent paper (containing an excellent list of references) by Macdonald and Katsura (1964).

Since complete chemical analyses are not available for most of the samples, and detailed mineralogic work has not been done, the required classification is based on the alkali-silica proportion. This was used indirectly by Tilley (1950), who plotted the tholeiitic lavas of Mauna Loa and Kilauea against the alkali basalts of Hualalai and Mauna Kea on an alkali-silica diagram, and was further defined by Macdonald and Katsura (1964), who drew an empirical boundary line between the tholeiitic and alkalic fields on an alkali-silica diagram. Not only does this provide a way of separating the two basalt types on a chemical basis, but was the most convenient method available in this study: The sodium content of the samples was determined by flame photometric methods and the silica by x-ray - fluorescence techniques (see Appendix B). These determinations were made in conjunction with the potassium analyses, and the sodium contents are listed with the potassium contents (Appendix C).

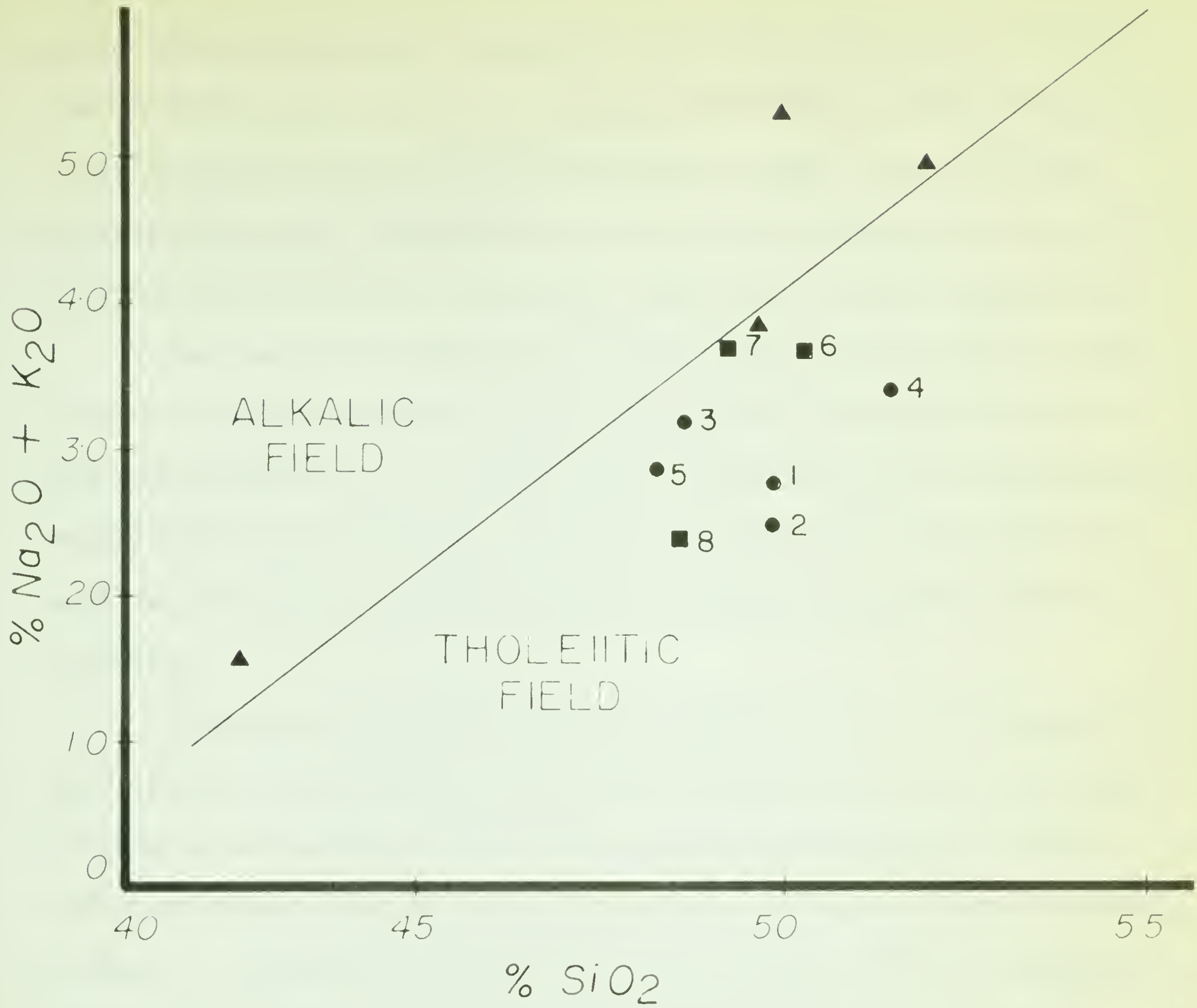
The percent total alkalis ($Na_20 + K_20$) and the percent silica ($Si0_2$) of

seventy-four dyke samples and four sill samples are also given in Appendix C.

In Figure 10, the average alkali content has been plotted against the average silica content for each dyke set and the sills. For the dyke samples, the average Na_2O content was found to be 2.36 percent; the average total alkali value is 3.0 percent.

From the alkali-silica plot, it can be seen that all the dyke samples fall below the line, and may therefore be classed as tholeiitic. Since some of the points (for example, point 7) fall very close to the alkalic field, consideration must be given to the possible errors in the determination of each constituent. The greatest error in the combined alkali content is estimated to be no greater than $\pm$ 2.0 percent and the maximum error for the silica content is $\pm$ 1.0 percent (based on the standard deviation from the mean of W-1 readings). Assuming these maximum errors, the dykes still fall in the tholeiitic field, except the northwest trending dykes of Ontario, which may possibly be in the alkalic field, if the silica value is less than that shown. The sill plots, as well, all appear to lie in the alkalic field. For the Yellowknife differentiated intrusive, included here, this may be attributed to differentiation, but this cannot be applied to the Ontario sills: AK 612 is from a four-foot thick sill, which was chilled throughout. In addition, this sill is thought to be closely related to the dykes in the same area, which all fall in the tholeiitic field. Not all the dykes plot individually in the tholeiitic field: AK 583, AK 584, AK 441, AK 449, AK 596, AK 604, AK 602, AK 649, and AK 251 are plotted in the alkalic field, although the swarms of which these are part are tholeiitic.

These findings are in partial disagreement with some of the conclusions reached by Fahrig et al. (in press), who found the N 10° - 40°W (Sudbury) dykes of Ontario and the N 0° - 30°W (Mackenzie) dykes of the Northwest Territories to be in the alkalic field. The plots obtained by the present author for these two dyke sets are very different. Fahrig et al. used data only from chilled dyke margin analyses, but if this is done for the dykes discussed herein, little relative changes exist in the



● DISTRICT OF MACKENZIE DYKES

1 N 70°-80°E Trend (10 samples)
2 N 30°-60°W Trend (9 samples)
3 N 0°-30°E Trend (5 samples)
4 N 0°-30°W Trend (7 samples)
5 N30° E Trend (2 samples)

■ ONTARIO DYKES

6 N10°W to N10°E Trend (4 samples)
7 N10° to 40°W Trend (7 samples)
8 N50°-80°E Trend (2 samples)

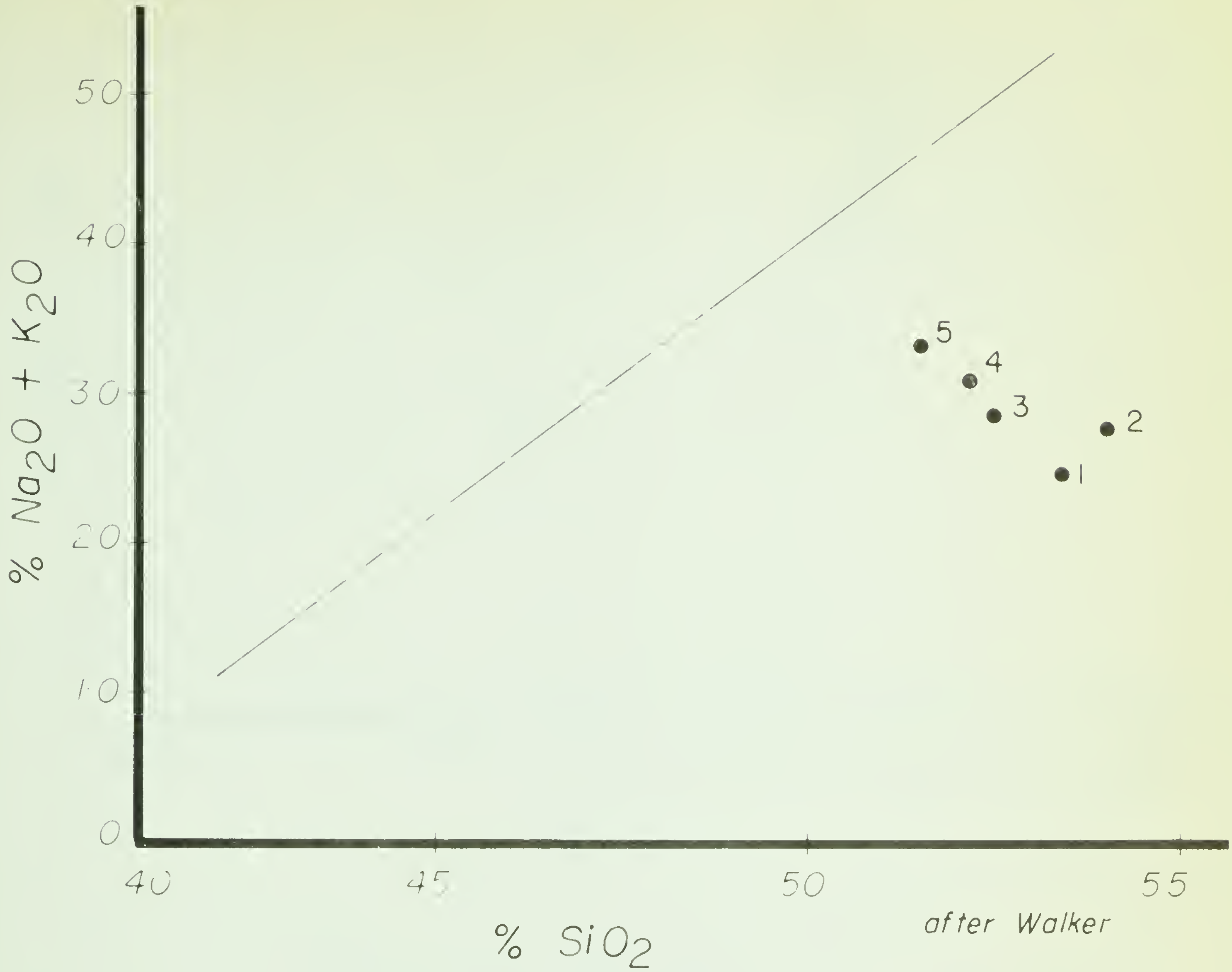
▲ SILLS

Figure 10. Alkali-Silica plot for Precambrian dyke sets and sills.

position of the plotted points. The position of plot of the N 30°E dykes of Ontario (Fahrig's Abitibi dykes) and the north-trending dykes of Ontario (Fahrig's Matachewan dykes) for both this report and Fahrig's work are very similar. Since it has been suggested (Payne et al. in press) that the northwest trending dykes of Ontario and the Northwest Territories are of the same swarm, these results are rather disappointing.

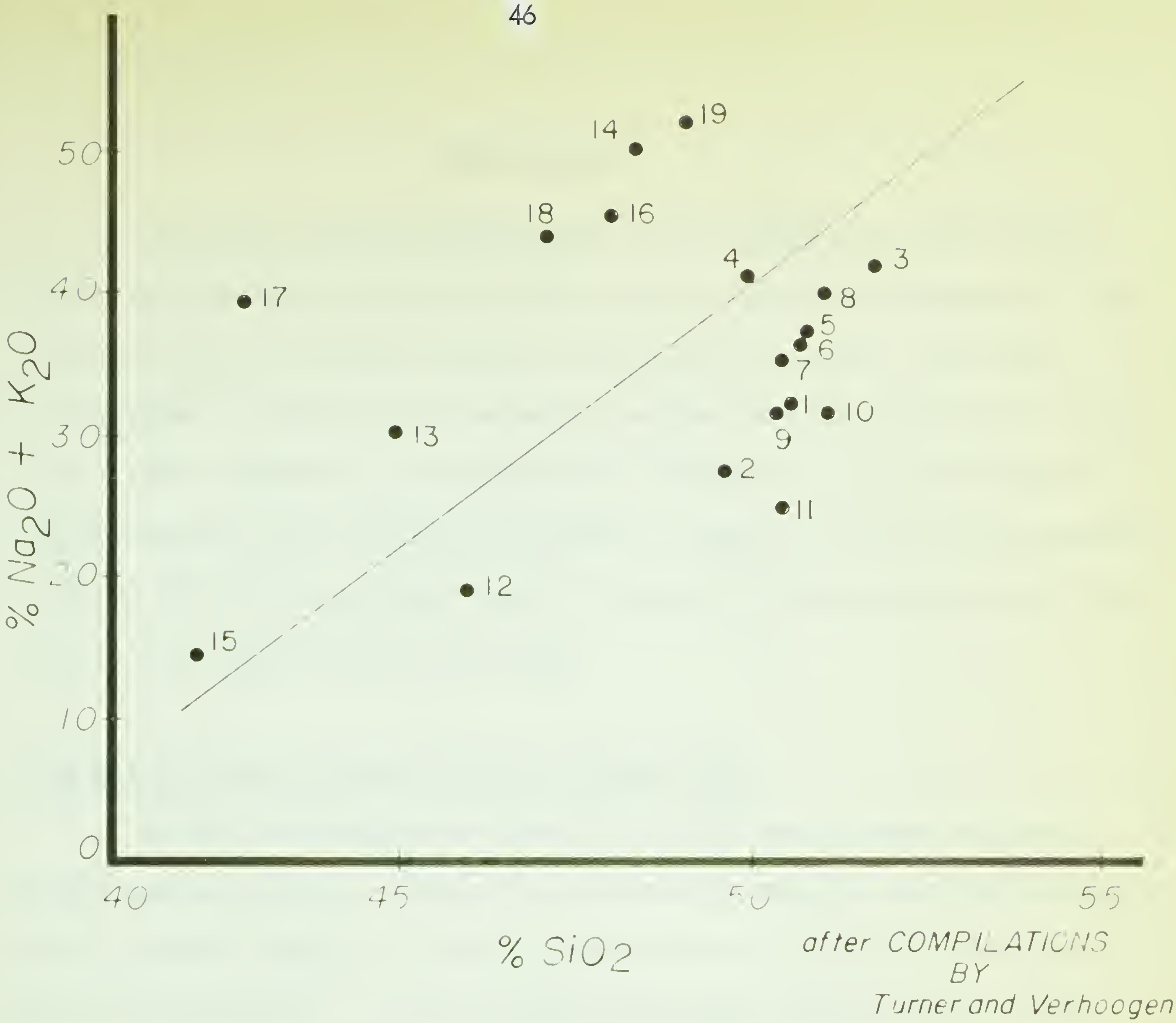
Examination of the alkali-silica proportion shows that the dykes are mostly tholeiitic in composition and that the dyke sets cannot be distinguished from each other with any certainty. This is in agreement with the conclusion (previously mentioned) reached by Green and Poldervaart (1955), although these results indicate that the comparison of the potassium content of dykes is perhaps a more hopeful method of correlation.

This method of classification can be applied to basaltic rocks throughout the world. Figure 11 shows the alkali-silica ratios of dolerites of Triassic-Jurassic age. A high silica and low alkali content is characteristic of all these basic intrusives. Alkalic and tholeiitic basalts of other intrusive and extrusive assemblages are plotted on Figure 12. These were compiled by Turner and Verhoogen (1960) from published data from many sources. It can thus be seen that the empirical line drawn by Macdonald and Katsura fits many situations, and that there is nothing anomalous about the dyke swarms of the Precambrian Shield of Canada.



1 average TASMANIA chilled dolerite
2 average ANTARCTICA dolerite
3 average KARROO dolerite
4 average PALISADES chilled dolerite
5 average SOUTH AMERICA dolerite

Figure 11. Alkali-Silica plot for Triassic-Jurassic dolerites.



THOLEIITIC BASALT:

1–3 Deccan basalts
4 Oregon basalts
5 New Jersey basalts
6 South African basalts
7 West Australian basalts
8 Tholeiitic magma-type (Kennedy, 1933)
9–12 Hawaiian lavas

ALKALI-OLIVINE BASALT

13 Olivine basalt magma-type (Kennedy, 1933)
14 Samoan basalts
15–17 Hawaiian lavas
18–19 Scottish basalts

Figure 12. Alkali-Silica plot for miscellaneous basalts.

PETROLOGY

Petrologic work of a reconnaissance nature was done on an intrusive body east of Yellowknife Bay, and on the diabase dykes of the District of Mackenzie. The purpose of this was to discover the general nature of the intrusives - their contact relationships, any differentiation tendencies, and the possibility of multiple intrusion. In most cases, radiometric work had been done on the samples, and it was hoped that the thin-section study would furnish information at least partly explaining discrepancies in dates. For this reason, special attention was given possible potassium sources in the rock, and the degree of general alteration.

THE YELLOWKNIFE DIFFERENTIATED INTRUSIVE BODY

In 1940, Hill designated this body as a "basic intrusive sheet" of olivine gabbro and quartz gabbro. Although the contacts of this body are mostly drift covered, and it is faulted throughout, an almost complete section is found on the north shore of Duck Lake (Figure 13b). In the field, black weathering, jointed, olivine-rich rocks cut by serpentine veinlets can be mapped for 160 feet along the shore line, followed by a ten foot transitional phase and a 480 foot exposure of gabbroic rock. In places, the gabbro appears diabasic, trachytic and granophyric in texture, and is cut throughout by carbonate veinlets carrying sulphides. The top contact with the meta-sedimentary rocks can be observed, and the dip, measured at the base, appears to be 10 - 15° east. This would give a total thickness of up to 1055 feet and a thickness of the basal olivine-rich layer of 24-36 feet, if the true thickness of the olivine-rich layer is present. However, the intrusive is tightly folded to the north of this, and other field relations indicate the situation is more complex: To the north (Figure 13a) a bore hole drilled from the top of a 75 foot cliff passed through 158 feet of the olivine-rich rock without reaching the lower contact. The drill hole was inclined at 70 degrees to the west, approximately perpendicular to the attitude of the "sill". Thus, the structural

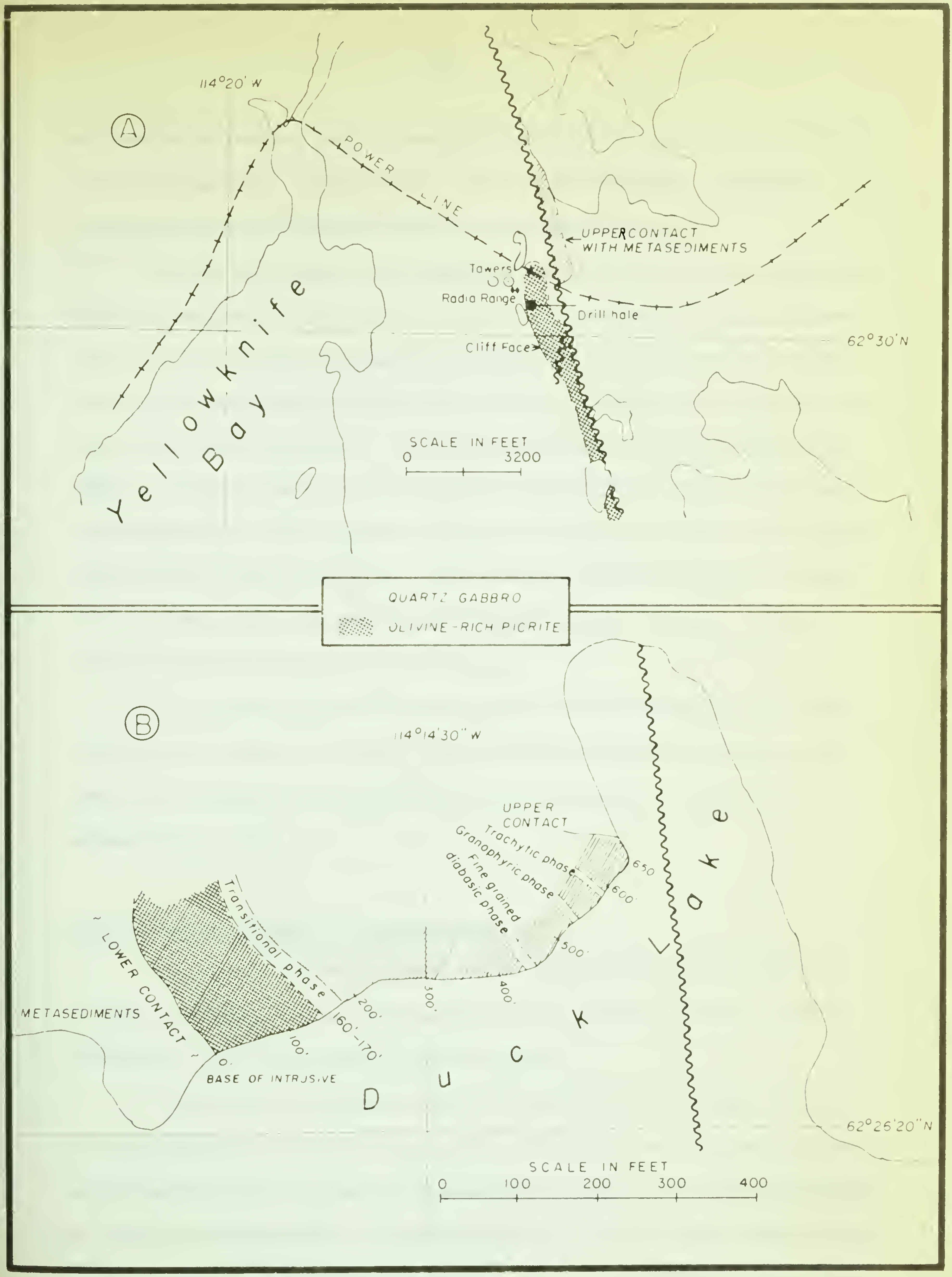


Figure 13. The Yellowknife Differentiated Intrusion exposed (A) near the drill site, Ptarmigan Road, and (B) along the north shore of Duck Lake.

relationships are obscure, and it is possible that the "sill" or "sheet" is an ethmolith or funnel-shaped body. Unfortunately, to the east of the drill site, the gabbroic rocks are separated from the olivine-rich rocks by a brecciated fault zone.

The two main types of rocks composing the intrusive body are an olivine-rich rock, best described as a picrite, and a gabbro. The term picrite is used in the same sense as by Smith (1962), who described picrite from the Muskox intrusion as a rock "differing from peridotite in its high olivine content (15-30%) and from gabbro in its high olivine content (20-50%)." The term gabbro is used as defined by Moorhouse (1959, p. 231) as "a medium to coarse-grained rock consisting of basic plagioclase and clinopyroxene. Olivine gabbro also carries olivine; quartz gabbro carries quartz". The picrite is the basal layer of the intrusive, and the quartz gabbro forms the upper part. It is the picrite layer which forms the apparently gently dipping, jointed, lichen-covered cliffs pictured in the frontispiece.

Thin sections were made from both major rock types sampled at Duck Lake, from the picrite exposed to the north (both cliff-face and bore-hole samples), and from the quartz gabbro lying to the east of the bore-hole site, in contact with metasedimentary rocks.

Picrite: Mineralogy and Textural Relationships

The average section contains about 50% olivine or serpentine, 20% clinopyroxene, 3% orthopyroxene, 25% plagioclase, and accessory magnetite, ilmenite, and biotite. The olivine content decreases upwards.

The olivine is all optically negative according to Hill, but some of the olivines examined by this author were positive. The olivine was extracted from one sample and the forsterite content was measured by the x-ray powder method described by Yoder and Sahama (1957): it was 76% forsterite. Since a universal stage was not used here, and it was impossible to determine the sign of many olivines with high 2V,

it is concluded that the olivine is both ferric and magnesian. The olivine occurs in rounded idiomorphic grains from 1/2 - 2 1/2 mm. in size, often enclosed poikilitically in large pyroxene grains (Plate 1, Figure 7) or clumped together with the pyroxene (Plate 1, Figure 8) in a mesh. No reaction rims surround the olivine grains. The olivine is commonly altered to serpentine (Plate 1, Figure 6), especially where serpentine veinlets cut the rock, and fractures (also filled with serpentine) radiate from the altered crystal into the surrounding grains.

The pyroxenes, all optically positive, seem to be of two main sorts, rare pigeonite, with a 2V of 20° - 30°, and augite. The augite occurs with a 2V of about 45° (augite-ferroaugite?) or with a very large 2V (diopsidic augite). The pyroxene generally occurs in large anhedral plates separated by blocky plagioclase crystals, (Plate 1, Figures 6, 7), although some early formed grains are perfectly euhedral. The pigeonitic augite crystals are fringed with an alteration zone of cloudy iron oxide, but the augite is remarkably free from alteration - the serpentine that alters the olivine so readily has no effect on the pyroxene (Plate 1, Figure 6). When it is altered, the pyroxene is replaced by a green uralitic hornblende or chlorite. No zoning was observed in these pyroxenes and only a few twinned crystals were found.

The plagioclase, all more calcic than An_{50}, has an average composition of labradorite. It occurs as stumpy blocks, from 1-2 mm. in size, has well-developed albite twinning, and it is always interstitial, never enclosed in pyroxene plates (Plate 1, Figures 6, 7, 8). Zoning is simple, and a single crystal may have a core of An_{70} and a rim of An_{30}, although most are zoned only near the margins from An_{55} to An_{50}. The feldspar is altered, sometimes completely, to sericite or white mica.

Accessory minerals include primary magnetite, titaniferous magnetite with exolved ilmenite (altered to leucoxene), rare apatite and rutile, calcite and sulphide ores. Biotite is found, all very closely associated with magnetite in this layer. It is reddish brown and strongly pleochroic (Plate 1, Figure 6). Very fresh and unaltered,

it is the probable source of most of the potassium in the whole-rock samples dated, but is too difficult to separate for a mineral date.

From the thin sections, it is apparent that olivine crystallized first, followed by pigeonitic augite, augite, and feldspar. Settling of the early-formed olivine probably provided the basal picrite layer.

One other interesting feature of the picritic zone deserves mention: serpentine occurs not only in veinlets but in occasional massive bands throughout the picrite (Plate 1, Figure 5).

Quartz-Gabbro: Mineralogy and Textural Relationships

An average section of the gabbroic phase of this intrusive contains 50-55% plagioclase feldspar, 30-35% clinopyroxene, 5-10% magnetite, 5-10% quartz, 3% biotite and variable amounts of olivine, potassium feldspar, and carbonate.

The pyroxene of the gabbroic zone is the major mafic mineral, forming in large (1-3 mm.) subhedral crystals against a background of plagioclase laths. Feldspar is rarely enclosed in the pyroxene. No pigeonite was found, but a diposidic augite ($2V = 65°$) and a ferroaugite are common ($2V$ 39° - 45°). Both are much altered to chlorite (Plate 1, Figure 4). A few crystals show zoning (Plate III, Figure 3) and twinning is common.

The feldspar occurs as laths from 2-6 mm. in length forming a thick mesh between pyroxene grains. Zoning is simple, but pronounced: where a plagioclase crystal is adjacent to quartz or a granophyric intergrowth, the zoning may pass from a core of An_{50} to a margin of An_{10-15} in extreme cases. In other instances An_{45} is the average composition measured. Albite and Carlsbad twinning is present (Plate III, Figure 3). The feldspars are much altered, mostly to sericite (Plate I, Figure 3). In some places, the trachytoid appearance of the rock (as at Duck Lake (Figure 13b) is due to the alignment of feldspars.

5-10% quartz is present in all the sections examined and for this reason, the gabbro is referred to as a quartz gabbro. The quartz is found as interstitial grains, and in granophyric intergrowths (Plate I, Figure 4) with albite and a small amount of potassium feldspar.

Olivine is present as well, in quantities up to 10% in some sections (Plate III Figure 3). In the upper zones, it is almost entirely altered to green antigorite and magnetite, which forms blebs along curved fractures. Less and less olivine appears as one goes up in the section away from the picrite, and often it is not present at all. In some sections, quartz and olivine appear together (Plate III, Figure 3), indicating disequilibrium.

Titano-magnetite varies in amount from 2-10%, closely associated with biotite (Plate 1, Figure 3). The biotite is rather scarce throughout most of the quartz gabbro. Rutile and apatite are the other accessories (Plate I, Figure 4).

The upper contact zones merit special attention (Plate I, Figure 1, 2). The contact seen at Duck Lake is very irregular; near the contact, coarse pegmatitic phases appear, both aplitic dykes and carbonate and quartz veinlets cut the rocks, and sulphide mineralization is apparent in segregated patches.

Biotite is abundant in both the contact gabbro and the baked sediments of the contact hornfels. It is fresh, unaltered, a pleochroic reddish-brown and makes up about 10% of the rock. At the contact, (Plate I, Figure 1) it occurs as long needles in the gabbro, but further from the contact, large plates appear (Plate 1, Figure 2).

Comparison with the Basistoppen Sheet

The Yellowknife differentiated intrusive may be compared with other layered, differentiated, intrusive bodies throughout the world, for example, the Muskox intrusion of the District of Mackenzie (Smith, 1962), the Palisade sill of the United States (Walker, 1940), the Shiant Isles sills of Scotland (Drever and

Johnston, 1953), and the Karroo dolerites of the Union of South Africa (Walker and Poldervaart, 1949). None of these, however, seems as close in comparison as a less famous basic intrusion in East Greenland, recently described by Douglas (1949) as intrusive into the upper part of the Skaergaard intrusion. This sheet was once regarded as a huge inclusion, the "Basistoppen raft" (Wager and Deer, 1939). It was later described as essentially a double-layered sheet (Hughes, 1956) consisting of a basal olivine-rich zone and overlying zones of pyroxene. Douglas' work revealed that the upper pyroxene ferrodiorite, thought by Hughes to be part of the Skaergaard intrusion, represents the uppermost parts of the Basistoppen intrusive sheet. Perhaps further detailed work will show that the Yellowknife differentiated intrusive body can be subdivided, or that it has an upper zone equivalent to the ferrodiorite, but in any case, these two simply layered intrusions are very comparable. In the following brief account of the Greenland intrusive sheet, the close similarities and the few differences between it and the Yellowknife intrusion are apparent.

All the field relations of the Basistoppen sheet are not clear, and no complete section has been discovered, although the differentiated, layered mass, about 400-500 m. thick, is exposed over about 4 km. The base of the sheet, where found, is highly irregular, and the attitude of the rocks, generally parallel to the Skaergaard layering, changes in some places (where the sheet becomes much narrower) to nearly vertical. Douglas correlated the incomplete sections examined (using the composition of the samples plagioclase cores), admitted the structural heights were approximate, and found that the sheet could be divided into four main zones.

The type of layering in the body is termed cryptic layering, and it is of two kinds, "continuous cryptic layering, i.e. the steady change in composition of the cumulus * phases, and discontinuous or phase change cryptic layering i.e. the abrupt appearance or disappearance of a particular cumulus phase". This type of layering is distinguished from rhythmic layering, in which there is a variation in

* Cumulus = primary precipitate.

proportion of the component minerals from layer to layer. The four main zones were recognized on the basis of phase change cryptic layering, and are, from lowest to highest, a gabbro-picrite (an olivine-rich rock with gabbroic affinities), a bronzite gabbro, a pigeonite gabbro, and a pyroxene ferrodiorite.

The gabbro-picrite zone consists of olivine-rich rocks near the base of the sheet. Mineralogically and texturally the rock is very similar to the picrite of the Yellowknife intrusion. It is composed of 40-45% olivine, 15-20% clinopyroxene, 30-35% plagioclase, 3-5% iron ore, up to 5% biotite, 3% chlorite, and traces of apatite. The olivine, occurring in rounded subhedral grains, subpoikilitically enclosed in augite, is altered to serpentine and opaques in some thin sections. There is a decrease in forsterite content (from Fo_{83} to Fo_{77}) as one goes upwards in the section. The clinopyroxene in the gabbro-picrite zone crystallized later than the olivine, but before the plagioclase. Little orthopyroxene is present.

Since the quartz gabbro of the Yellowknife intrusion was not studied in great detail, it is more difficult to compare it with Douglas' upper zones of bronzite gabbro, pigeonite gabbro, and pyroxene ferrodiorite, although the general impression is similar to that gained from the Yellowknife body.

The olivine disappears in the two central zones of the Basistoppen sheet, the plagioclase increases to make up 50-60% of the rock, the augite also increases slightly to 30-35% (60% in one zone), and orthopyroxene (bronzite) and pigeonite appear in the appropriate sequences. Quartz and micropegmatite are found (up to 5%), and small amounts of biotite are present. The clinopyroxenes of these two zones are subhedral, average 2 mm. across, and often display simple twinning. They have altered crystal margins. The plagioclase feldspar changes in composition from An 73 to An 47 from the base of the bronzite gabbro layer to the top of the pigeonite gabbro layer. It occurs as subhedral tabular or lath-shaped crystals up to 5 mm. in length, has zoned margins, and is extensively altered to sericite. The iron ore

content reached 9% in some parts of these zones, but biotite is generally scarce. In the upper zone, the pyroxene ferrodiorite, the olivine reappears (10-20%), augite and plagioclase vary from 10-30% and 30-60% respectively, and the quartz and micropegmatite content may reach 10-15%. The iron ore content is high: up to 10%. Some aspects of this zone are of special interest: the olivine is mostly altered to green chlorite, serpentine, or iron ore. Olivine of this same character appears in a section taken from a sample fifty feet below the upper contact at Duck Lake, after an absence in the section far over 200 feet. In addition, the pyroxene ferro-gabbro has a high content of free quartz and micropegmatite also characteristic of the Yellowknife quartz gabbro.

The upper contact was not found for the Greenland sheet, although acid veinlets appeared in the uppermost rocks examined.

Chemical Analyses

Chemical analyses for the Yellowknife differentiated intrusive are restricted to two: one from the picrite (BU-2 '47) and one from the lower part of the quartz gabbro (BG-1 '47)(Plate III, Figure 3). Unfortunately, no analysis has been completed on the upper part of the quartz gabbro, nearer to the contact. These two available analyses are given in Table 4 together with two analyses from the Basistoppen sheet. The gabbro-picrite analysis appears as given by Douglas for the gabbro-picrite zone. One complete analysis for the bronzite gabbro and five partial analyses for the bronzite gabbro and the pigeonite gabbro have been combined, and the average listed in Table 4 as a "bronzite-pigeonite gabbro".

The analyses for each rock type are remarkably similar. The picrite of Yellowknife and the picrite-gabbro of Greenland occupy the same relative positions in their respective intrusive bodies, and are petrologically and chemically almost too similar! It remains as a future task to discover whether or not the quartz gabbro of

TABLE 4

CHEMICAL ANALYSES OF DIFFERENTIATED INTRUSIONS, YELLOWKNIFE AND GREENLAND

	Quartz Gabbro BG-1 '47 Yellowknife	Bronzite-pigeonite Gabbro Greenland	Picrite BU-2 '47 Yellowknife*	Gabbro-picrite (Douglas) Greenland
SiO_2	49.45	51.03	42.58	43.00
TiO_2	1.79	2.11	.38	.22
Al_2O_3	14.48	15.82	7.30	8.16
Fe_2O_3	1.75	2.31	3.22	1.73
FeO	9.40	9.26	14.41	11.32
MnO	.16	.16	.20	.19
MgO	5.78	4.86	21.32	24.16
CaO	10.89	9.37	5.13	6.17
Na_2O	2.87	3.22	1.27	.97
K_2O	.83	.52	.37	.49
P_2O_5	.05	.10	.13	n.d.
H_2O+	.68	1.21	2.51	1.81
H_2O-	.08		.47	
CO_2	1.84	n.d.	n.d.	n.d.
S	n.d.	n.d.	.10	n.d.
Ni	n.d.	n.d.	.20	n.d.
Cr_2O_3	n.d.	n.d.	.18	n.d.
	100.05	99.97	99.76	99.53
			.05	
	100.05	99.97	99.81	99.53

** C.I.P.W. Norms

		Quartz Gabbro BG-1 '47 Yellowknife	Bronzite-pigeonite Gabbro Greenland	Picrite BU-2 '47 Yellowknife*	Gabbro-picrite (Douglas) Greenland
Q		.70		-	-
or		4.84		2.06	2.78
ab		24.31		10.69	8.38
an		24.11		13.31	16.40
	wo	7.49		4.69	5.92
di	en	3.83		3.90	4.10
	fs	3.47		1.44	1.32
hy	en	10.62		8.24	3.80
	fs	9.65		3.06	1.32
ol	fo	-		30.87	36.40
	fa	-		16.82	12.85
mt		2.55		-	2.55
il		3.47		.73	.46
ap		.17		.34	-
pr		-		.18	-
cc		4.18		-	-
water		.76		2.98	1.81

* Analysts - H. Baadsgaard and A. Stelmach
** Calculated from Washington (1917)

Yellowknife has differentiated into more than one layer, for the average composition of the equivalent rocks of the Greenland sheet is very close, suggesting that the same type of situation could have developed in both intrusive bodies.

The normative compositions of the two Yellowknife samples were calculated and are also given in Table 4. Douglas provided the norm for his gabbro-picrite analysis, and it is given here as well, for comparison.

One of the major advantages of having these norms available is that it is possible to again attempt a classification of the Yellowknife intrusion as either tholeiitic or alkalic, according to the classification of Yoder and Tilley (1962). Although Yoder and Tilley divide the basalts into five groups according to their normative composition, tholeiitic basalts can be broadly distinguished from alkali basalts on the basis of silica undersaturation (Figure 14). Since Macdonald and Katsura (1964) state that their empirical line, based on the alkali-silica ratio, probably falls very near the border between the alkali and the tholeiitic fields on this diagram, it is useful to use this normative method. The absence of nepheline in the norms (Table 4) establishes that both samples are of the tholeiitic magma type, as is the basal part of the Greenland sheet. It is interesting to note that both Yoder and Tilley (1962) and Macdonald and Katsura (1964) have concluded that the presence or absence of normative hypersthene is not suitable as one of the primary criteria for this broad classification of magma type.

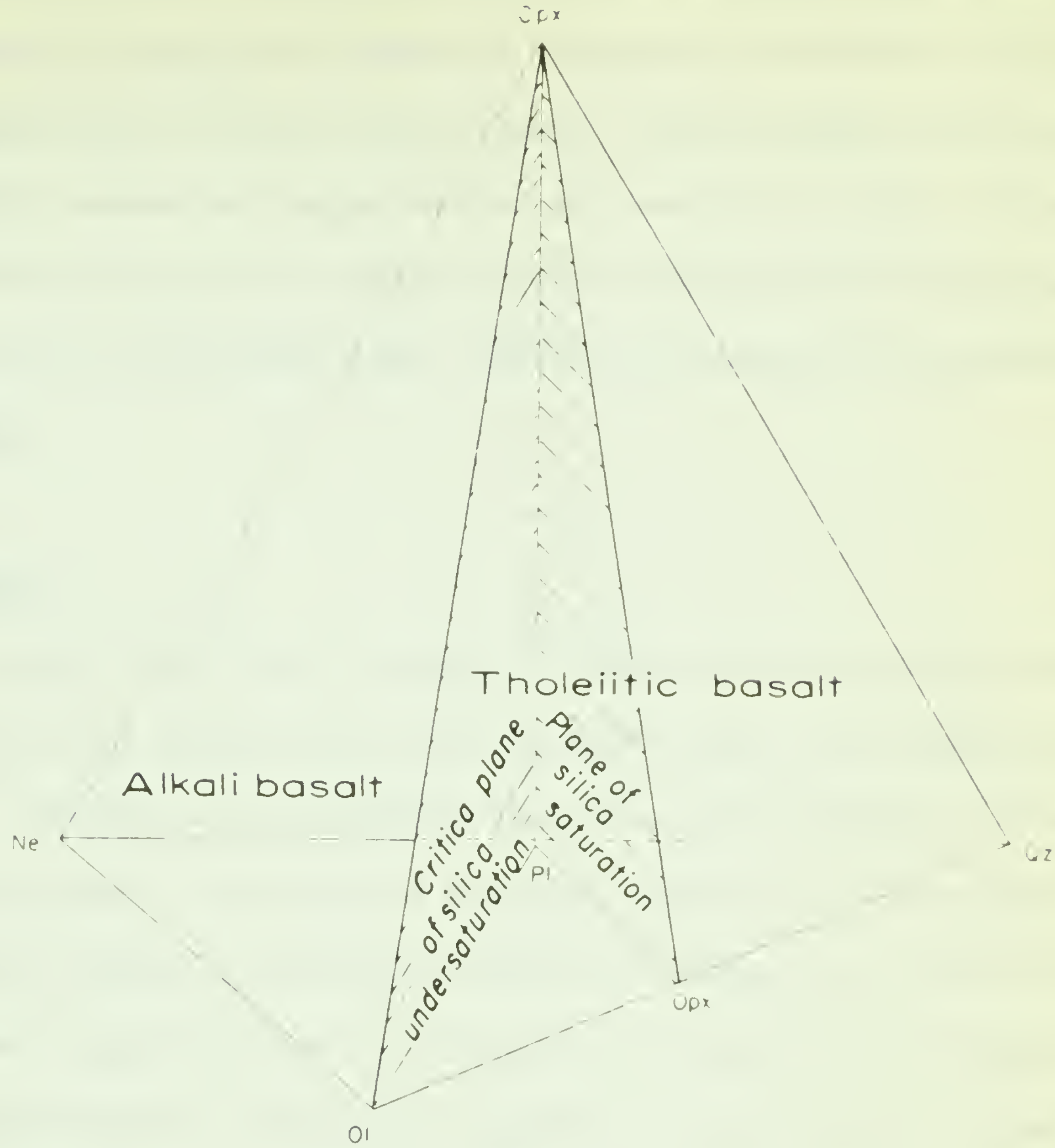


Figure 14. Normative tetrahedron for basalts composed of plagioclase, clinopyroxene, orthopyroxene, olivine, nepheline, and quartz, showing the two major basalt fields (separated by the critical plane of silica undersaturation).

THE DIABASE DYKES OF THE DISTRICT OF MACKENZIE

Diabase is defined as the hypabyssal equivalent of basalt (Moorhouse, 1962). As such, it has the same mineralogical composition as basalt, and the same fabric, but it is medium to coarse-grained rather than fine-grained and basaltic. As the dyke centre is approached, the grain size increases. Since the dykes have the requisite mineralogical composition (plagioclase and pyroxene with or without olivine and quartz) and the characteristic diabasic or ophitic texture (as defined by Moorhouse, 1962), they are called diabase dykes. This term is equivalent to the term dolerite of British usage.

Previous Work

A paper by Gill and L'Esperance in 1952 was the first comprehensive report published about the diabase dykes in the Canadian shield, and included a section on petrology. The dykes were divided into three types, quartz diabase, olivine diabase, and ordinary diabase, on the basis of presence or absence of olivine or quartz or both. No significant regional variations were found: the feldspars of all three rock types were similar, augite was present in all the rocks, orthopyroxene and pigeonite were more rare and sporadic in occurrence, magnetite was more abundant in quartz diabases and ilmenite in ordinary diabases. All the dykes showed diabasic or ophitic texture, the grain size ranged from fine at the chilled margins to coarse in the dyke centre. In general, then, the dykes were all quite ordinary diabases.

On a more local scale, Wilson (1949) made a petrologic study of the dykes of the Yellowknife greenstone belt, for the purpose of determining whether any difference could be detected in the two sets then recognized, and therefore whether it was possible to correlate the dykes petrologically. As previously mentioned, he could find no outstanding differences. The average composition of the dykes was found to be 45 to 50 percent pyroxene (sometimes zoned), 45 to 50 percent plagioclase

(always zoned), 5 to 10 percent opaque oxides and sulphides, with quartz, apatite, and a little biotite. Wilson did not encounter olivine in any sections, nor did he find any positively identifiable pigeonite. Most of the optic axial angles (measured on a universal stage) were from 40 to 50 degrees, and the pyroxenes were accordingly identified as augite. Plagioclase was found to show zoning from An_{75} to An_{25} in the most extreme cases. Less than 2 percent biotite was present in all cases, primary quartz and micropegmatitic quartz were found in nearly all specimens. The magnetite and ilmenite contents were variable; up to 10 percent was found in some specimens. Wilson found pyroxene altering to chlorite, clinozoisite, and chrysotile, plagioclase altering to zoisite, secondary white mica, chlorite, kaolinite, clinozoisite and quartz, and magnetite and ilmenite to hematite and leucoxene.

From his work, Wilson concluded that the pyroxene began to crystallize first in most of the dykes, since he observed euhedral augite phenocrysts in a matrix of plagioclase laths, and found large pyroxene grains which did not contain any plagioclase crystals. However, he also admitted observing ophitic texture in some sections.

Present Work

Thin sections of diabase dykes of all trends in each of the areas studied in the District of Mackenzie have been examined at this time. Once more, one of the main purposes of this was to find an explanation for the potassium-argon dates obtained for the various samples.

Taken together, these diabase dykes show all of the features of most diabases. For this reason, a general description of mineralogical and textural relationships is given below for dyke contacts and dyke centres, followed by a separate discussion of certain individual cases.

At the contact the dykes commonly show a glassy or very fine-grained basaltic

matrix in which there are phenocrysts of olivine, pyroxene, and plagioclase, up to three millimetres in size. The contact rock is recrystallized in most cases (Plate II Figure 2). On the average, the phenocrysts occupied 25 percent of the contact rock: plagioclase laths formed the major phenocrysts, and were generally smoothly aligned parallel to the contact (Plate II Figure 1, 2) or caught together in a cluster, often with olivine and pyroxene.

Only a few of the dykes contained olivine, but, when present, it was the first mineral to crystallize. Plagioclase followed. Pyroxene never appeared as phenocrysts to the exclusion of plagioclase; in some sections, only a few pyroxene crystals could be found in the entire thin section, while in others, equal quaitities of plagioclase and pyroxene are present as phenocrysts. When pyroxene was present in quantity, it occurred as euhedral, twinned crystals. The plagioclase was always euhedral, and also twinned. Alteration was slight in most cases - the plagioclase is partly sericitized or serpentinized and the pyroxene remains fresh in appearance. Some contact zones, however, have been much altered (Plate II, Figure 3) and only the plagioclases are recognizable, by shape.

More than two centimetres away from most contacts, the basaltic groundmass has coarsened slightly and it is possible to distinguish the texture in the matte between phenocrysts (Plate II Figures 5, 6). Biotite, if present, occurs in small, rounded crystals, and in the quartz-rich diabases, zones of granophyre can be found, even when olivine is present (Plate II, Figure 6). A few inches from the contact, the grain size of the groundmass has increased so that "outsize" phenocrysts are not present and the rock has a smooth diabasic texture throughout.

In preparing contact samples for dating, a slice of rock was used 1 to 3 mm. distant from the contact. In the older rocks of the Yellowknife area, biotite, if present at all in a dyke, was encountered in greatest abundance in this zone of the dyke, but in such small grains and in such small quantity, that it would be very

difficult to obtain a mineral concentrate for dating purposes.

Textural relationships are clearer in the coarser grained dyke centres. Except in very wide dykes (greater than 150 feet wide), the grains were medium-sized, and showed a diabasic texture. In the wider dykes, however, the texture tended to become more ophitic, although the plagioclase always remained as laths, never becoming blocky (Plate III, Figures 1, 2). In cases where the pyroxene occurred as large poikilitic plates, the enclosed plagioclase laths were very small compared to those outside the pyroxene. When olivine was present, it was as rounded or euhedral grains, in isolated patches (Plate III, Figure 1). Quartz was always interstitial, and, generally part of a granophyric intergrowth (Plate III, Figures 6, 7, 8).

Mineralogically, the dykes are very uniform, with about equal amounts of plagioclase and pyroxene (or a slight excess of plagioclase), making up 80 to 90 percent of the rock.

The lath-shaped plagioclase is twinned according to the Albite, Carlsbad and Pericline laws, and is nearly universally zoned. The zoning is both simple and oscillatory. Most crystals are zoned from An_{80} at the core to An_{55} at the rim, but where a plagioclase is bordered by granophyre, the zoning ranges downward to An_{30-35}. All these features are illustrated in Plate II, Figures 7 and 8. The feldspar alters most often to sericite or white mica, rarely to epidote.

The pyroxene is of two varieties, augite and pigeonite. The pigeonite was identified by its small optic axial angle (2V less than 30 degrees), but the relative proportions remain unknown, since there was little difference in alteration or appearance in the two sorts of clinopyroxene (Plate III, Figure 4). The pyroxenes are very often twinned (Plate III, Figure 5). Alteration products include serpentine, chlorite, and uralitic hornblende.

The olivine, occurring in quantities up to ten percent, is usually zoned (Plate III, Figure 1) or heavily altered (Plate III, Figures 1, 2) to serpentine or

magnetite.

Quartz was found in nearly all the sections examined. It was always interstitial, usually in a granophyric intergrowth of quartz and feldspar (Plate II, Figure 8; Plate III, Figures 6, 7, 8). The feldspar in these micropegmatites was identified as albite (when twinning was present) or orthoclase.

Apatite crystals and rutile needles (Plate III, Figure 7, 8) are found as accessory minerals with magnetite, ilmenite (altered to leucoxene) and hematite. Some samples were rich in carbonate, both primary and secondary.

No consistent features, texturally or compositionally, could be found in the diabases of the various trends, although the presence of olivine and pigeonite was confirmed. The only dykes to contain olivine (or its altered relict) were those of Set I and Set IV of the Yellowknife area, and the youngest northeast trending dyke near Coronation Gulf. Not all the sections taken from the same olivine-bearing dyke showed olivine and some were so badly altered that little could be positively identified. The need for more than one thin section from a given dyke is thus seen.

A suite of seven samples (AK 467 to AK 473) taken by R. A. Burwash and F. A. Campbell from contact to contact across a 300 foot wide diabase dyke north of Prosperous Lake best illustrates all these things. It will be noticed that many Figures in the accompanying Plates are taken from this dyke profile, although these features are found in the other dykes as well.

All these samples were dated as whole rock samples, and the results (given in Figure 15 in the next chapter), can be considered in the light of information obtained from thin sections concerning the source of the potassium and the condition of the minerals. The two contact samples both contain abundant biotite flecks, and do not appear very much altered in hand specimen or thin section. They give radiometric dates believed closest to the age of intrusion of the dyke. The centre dyke samples showed very little biotite, and most of the potassium is believed to be in the alteration

products - sericite or deuteric hornblende. Some samples with a high K_2O content, such as AK 470 and AK 471, have a granophyre content of from 5 to 10 percent, indicating that the potassium may be contained in the feldspar of the intergrowth. In general, centre whole-rock samples tended to give lower dates than the corresponding chilled-margin samples.

One of the most interesting observations was with respect to the degree of alteration. Samples AK 470 and AK 471 were both badly altered, but managed to retain much more argon than the fresh, unaltered AK 472. To the southwest of Prosperous Lake, samples from the same dyke showed similar results: AK 586 was almost totally altered (Plate II Figure 3) and yet gave the same date as AK 579, a relatively unaltered rock. This would suggest that the general state of alteration does not have as much influence as would be expected on the date obtained from a whole rock sample. A possible explanation is that unaltered, granophyric feldspar would tend to leak argon, while the sericite would retain its argon. Thus, if the granophyre was formed, and remained unaltered, a lower date would be obtained than if sericitic alteration occurred as the final event, the sericite collecting and holding argon.

When information gained from the study of this dyke was applied to samples taken from other areas of the District of Mackenzie, it was expected that the best results would be obtained from biotite-bearing contact rocks. In most cases, this was true. The presence of biotite seems to be datably desirable - when it appeared as late, fresh, deuteric biotite in an otherwise altered rock (such as AK 575) it provides suitable material.

The younger dyke sets did not show such wide range in radiometric dates from sample to sample in the same dyke, or from dyke to dyke in the same set, and it is not possible to attempt to correlate dates obtained with the rock observed in thin section, as was done for the older dykes. However, among the dykes of Set III,

all kinds of samples were used - centre dyke samples, contact dyke samples, samples much altered, and samples with or without visible biotite in them. Since the dates obtained from these various kinds of whole-rock samples were consistent, it is apparent that some other factor, such as periodic resetting of the radiometric clock, is operative, in addition to potassium source or rock condition.

RADIOMETRIC DATES AND GEOLOGIC AGE

Radiometric Dates

The dating of diabasic rocks has been well discussed by Burwash *et al*. (1963). The radiometric dates presented here have been done mostly on whole-rock samples of diabase dykes. For a few samples, biotite or hornblende could be separated to give a mineral date. When possible, samples were taken at the contact or in the chilled margin zone. The exact sample locations are given in Appendix A, arranged in order of increasing AK number, but approximate locations are marked on the maps throughout the report and in the pocket, together with the AK number of the sample, the radiometric date in millions of years, and the material dated. Abbreviations were used on the maps as follows: gr indicates that the sample was from granite at the contact; W, that a whole-rock dyke sample was used; b or hb, that mineral separates, biotite or hornblende, were dated. The methods for potassium determination, argon extraction, and age calculation are given in Appendices B and C.

Some of the data from this study was presented as Canadian Contribution No. 58 to the International Upper Mantle Project, and will be published in the annals of the International Geological Union. Differences in the dates published are due entirely to recalculation.

The results are tabulated in Table 5. Samples are grouped according to area and trend, and, as before, the asterisk indicates that the work on a particular sample was not done entirely by the author. The potassium-argon dates have been rounded off to the nearest five million years. The assumed deviation in the dates is $\pm$ 5 percent. Duplicate runs for two samples (AK 514 and AK 474) indicate that this is reasonable precision; the reproducibility of Ar^{40}/K^{40} determinations has been discussed by Baadsgaard et al. (1957). With few exceptions (AK 590, AK 603, AK 606, AK 651) the amount of radiogenic argon is over eighty percent. Dates of the samples with low potassium content (less than 0.20 percent) have the largest

TABLE 5

POTASSIUM-ARGON AGE DATA*

Sample	K%	Ar^{40}/K^{40}	Radiogenic Argon %	K-Ar date m.y.
N 70° - 80°E Trend, Yellowknife - Lac de Gras Areas:				
AK 515	0.231	0.1824	91.4	1830
AK 536	0.361	0.1038	86.0	1240
AK 579	0.571	0.1644	94.4	1720
AK 582	0.812	0.0925	96.2	1140
AK 583	1.932	0.1509	96.9	1615
AK 586	0.591	0.1019	96.0	1225
AK 587	0.160	0.1565	77.3	1655
*AK 467	0.291	0.1982	97.0	1925
*AK 468	0.331	0.1580	94.0	1665
*AK 469	0.274	0.1406	94.0	1540
*AK 470	1.203	0.1731	99.0	1770
*AK 471	1.616	0.1603	98.6	1680
*AK 472	0.561	0.0680	89.4	900
*AK 473	0.441	0.1893	99.0	1870
AK 584	2.024	0.1572	98.0	1665
AK 580	0.400	0.1710	88.9	1750
*AK 261	0.245	0.2690	91.5	2310
*AK 446	6.336	0.1852	99.6	1845
*AK 450	0.521	0.1947	97.3	1905
AK 466	0.571	0.1508	98.0	1615
AK 514	0.458	0.0752	94.2	970
		0.0839	91.2	1060
*AK 442	0.421	0.1924	96.0	1890
*AK 447	0.429	0.1351	92.0	1500
*AK 453	0.434	0.1296	94.0	1455
*AK 440	1.022	0.2560	99.6	2250
*AK 443	7.624	0.2790	96.0	2360
AK 518	4.824	0.2846	99.5	2390

*Constants: $\lambda_e = 0.589 \times 10^{-10}/yr.$

$\lambda_\beta = 4.76 \times 10^{-10}/yr.$

$K^{40}/K = 0.01181$ atomic percent

Sample	K%	Ar^{40}/K^{40}	Radiogenic Argon %	K-Ar date m.y.
N 30° - 60°W Trend, Yellowknife Area:				
AK 574	0.200	0.1532	94.5	1630
AK 575	0.331	0.1420	94.6	1550
AK 576	0.451	0.1301	95.6	1460
AK 577	0.641	0.0995	90.9	1205
AK 523	0.220	0.1842	88.1	1835
AK 531	1.006	0.1448	60.3	1570
AK 537	0.611	0.1064	93.3	1265
AK 585	0.210	0.2029	90.4	1955
AK 589	0.090	0.3088	84.9	2500
AK 590	0.190	0.1632	78.2	1700
AK 592	0.802	0.1305	89.9	1545
N 0° - 30°E Trend, Yellowknife-Lac de Gras Areas:				
*AK 439	0.962	0.1448	96.0	1585
AK 465	0.511	0.1551	98.5	1645
AK 525	0.220	0.2051	95.8	1965
AK 527	0.862	0.1573	96.5	1660
AK 595	0.471	0.1440	94.1	1565
*AK 474	0.120	0.1653	88.0	1715
		0.1650	90.8	1713
AK 441	1.403	0.1426	97.0	1555
AK 449	1.379	0.1336	98.0	1485
AK 519	0.441	0.0942	82.1	1155
N 0° - 30°W Trend, Lac de Gras, Point Lake, Coronation Gulf Areas:				
*AK 444	0.626	0.087	95.0	1065
*AK 445	0.871	0.0904	94.5	1120
*AK 448	0.657	0.0695	89.7	920
*AK 452	0.946	0.0788	94.7	1010
AK 513	1.353	0.0793	92.4	1015
AK 597	0.501	0.1041	95.3	1245
AK 598	0.451	0.1046	93.8	1250
AK 600	0.661	0.1033	91.8	1235
AK 604	1.543	0.0903	95.6	1120
AK 610	1.022	0.677	98.7	935
AK 613	0.601	0.1032	88.8	1235

Sample	K%	Ar^{40}/K^{40}	Radiogenic Argon %	K-Ar date m.y.
Yellowknife Differentiated Intrusive:				
AK 463	0.476	0.1978	98.0	1925
AK 520	0.603	0.2130	99.0	2015
AK 464	1.363	0.1700	99.0	1745
AK 497	5.763	0.2266	100.0	2090
AK 524	0.479	0.1338	96.9	1490
N 30°E Trend, Coronation Gulf Area:				
AK 601	5.481	0.0470	98.4	665
AK 602	0.812	0.0490	98.9	680
AK 603	0.162	0.0462	63.4	655
AK 606	0.210	0.0495	74.5	695
N 10°W to N 10°E Trend, Ontario:				
AK 647	0.341	0.1994	94.3	1930
AK 648	0.531	0.1719	91.1	1760
AK 649	1.193	0.1355	97.6	1500
AK 650	1.213	0.1139	94.9	1325
AK 653	0.591	0.1017	84.5	1220
N 10° - 40°W Trend, Ontario (and Sill)				
AK 616	1.363	0.0894	91.9	1110
AK 620	1.440	0.0908	98.6	1123
AK 611	2.516	0.0768	96.9	1100
AK 651	0.985	0.0881	32.8	1100
AK 612 (sill)	1.092	0.0826	94.3	1045
N 50° - 80°E Trend, Ontario:				
AK 652	0.160	0.1040	82.5	1290

error, owing to the difficulties experienced in making the critical potassium determination. In these cases, a precision of $\pm$ 10 percent is more realistic, and usually the resulting difference of 100 to 200 million years in date does not alter the geologic interpretation.

Geologic Age

The geologic age sought here is the time of intrusion of the dykes. Since no major metamorphic events have occurred since their emplacement, the radiometric (apparent) date will be the same as the age of intrusion and cooling of the dyke if the following conditions are satisfied:

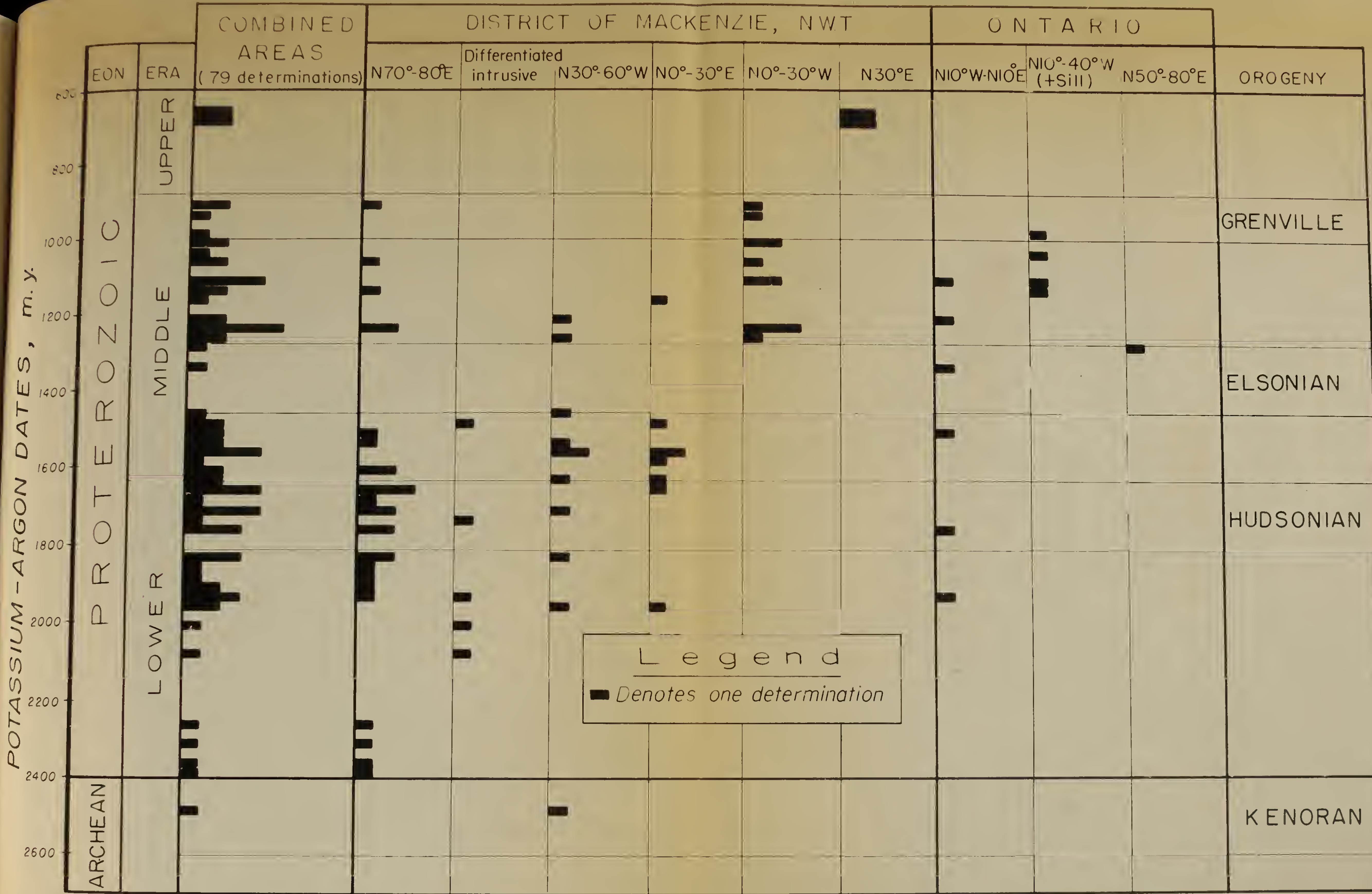
1. Decay constants must be known accurately.
2. The isotopic abundance of the radioactive parent must be uniform in the lithosphere.
3. Sampling must be representative.
4. Analytical measurements must be accurate.
5. Daughter contamination must be absent or insignificant.
6. Gain or loss of parent or daughter from a system must not have occurred.

The last of these is the most significant factor in considering the meaning of the dates obtained in this study. The problem of analytical accuracy has already been treated.

The potassium-argon dates given in Table 5 are presented in histogram form in Figure 15.

In the first column, 79 determinations from rocks of all areas are given. (These include 2 dates from the Yellowknife area not listed in Table 5, i.e. AK 528 and AK 530). This histogram appears to show four main periods of dyke intrusion at 2300-2400 m.y. ago, 1600-1800 m.y. ago, 1100-1200 m.y. ago, and 650-700 m.y. ago. Generally, the periods of dyke intrusion seem to be inter-orogenic - that is, in the time intervals between the major orogenic divisions of the Shield.

In succeeding columns of Figure 15 these dates have been separated,



POTASSIUM - ARGON DATES ON BASIC INTRUSIVE ROCKS OF THE CANADIAN SHIELD ACCORDING TO AREA AND TREND OF INTRUSIVE

according to area and trend of the dykes, and it becomes obvious that there is considerable variation in dates for a given area and trend.

If the earliest dates for each set are considered nearest to the actual time of intrusion, several periods of basic intrusion were initiated in the Shield during Precambrian time. These periods are indicated in Table 6. Only one date is available for a N 50° - 80°E dyke in Ontario, and this "set" is therefore not included.

Throughout this report, the diabase dyke swarms have been treated as sets on the assumption that all the dykes of parallel strike were probably emplaced during the same period of intrusion. There is no definite field evidence in the district of Mackenzie indicating multiple intrusion along a given trend, and the scatter in dates prevents recognition of different episodes, if any, within a dyke swarm. Emplacement may have occurred at one time, or in several periods extended over a few hundred million years. Field evidence available in Ontario suggests that the situation there is more complex and that the assumption described above cannot be made. Since most of the work done here concerns District of Mackenzie dykes, the classification of dykes by area and trend is followed for convenience, although future work may show that this is not justifiable in all cases.

Having established the time of initial intrusion of the dyke swarms, it is possible to reconsider the dates obtained from individual dykes. The older dykes show much more "scatter" than the younger dykes. For example, the first fourteen samples listed in Table 5 (AK 515 to AK 473 inclusive) are taken from the same dyke in the Yellowknife area (see map in pocket). The radiometric dates range from 1925 m.y. all the way down to 900 m.y. If the six dates from two parrallel dykes to the south are considered, the range increases to become 2310 m.y. to 900 m.y.

In younger sets, however, such as the northwest trending sets of the District of Mackenzie and Ontario, there is not nearly so wide a scatter in radiometric dates.

The later dates, following the "date of initial intrusion" can be collectively

TABLE 6

PROBABLE PERIODS OF BASIC INTRUSION IN THE PRECAMBRIAN SHIELD

Area and nature of intrusion	Time of initial intrusion m.y. ago
District of Mackenzie dykes N 70° - 80°E trend (Set I)	2200-2400
Yellowknife Differentiated Intrusion	1900-2100
District of Mackenzie dykes N 30° - 60°W trend (Set IV) N 0° - 30°E trend (Set II)	1800-2000
Ontario dykes N 10°W to N 10°E trend	
District of Mackenzie dykes N 0° - 30°W trend (Set III)	1100-1250
Ontario dykes (and sill) N 10° - 40°W trend	
Coronation Gulf dyke	600-700

examined. In general, for each set, as for individual dykes within the set, the greatest concentrations of dates appear in the intervals 1800 to 1500 m.y. ago and 1200 to 1000 m.y. ago. These periods roughly correspond to the periods of peak intensity shown in the first column of Figure 15 and to periods of major orogeny in the Precambrian shield, as given by Stockwell (1962, 1964a, 1964b).

In contrast, the dates chosen for the time of initial intrusion do not correspond to these major orogenic periods. Relating these observations to the last condition which must be fulfilled in obtaining meaningful results from radiometric dates, it appears that there has been a loss of daughter product by diffusion. The grouping of dates indicates that the older dykes are more likely to have lost argon by leakage than the younger dykes, and that this loss may be effected by "echoes" of major metamorphic or tectonic events in other shield areas, or by local periods of

faulting and thermal activity. This is illustrated in the Yellowknife-Prosperous Lake Area, where several periods of faulting and intrusion have occurred, and there is some evidence of post-dyke low temperature thermal events: in one locality east of Ryan Lake, an aplitic vein with "comb quartz" and some sulphide mineralization cuts a diabase dyke. The scatter in dates of the dykes reflects this tectonic "noise", however gentle it may be. The same noisy environment is found in the Porcupine-Timmins area, where the north trending dykes in particular show the effect.

In one sample, AK 589, taken at a dyke contact underground in the Con Mine at Yellowknife (2300 level), there is a possibility that excess radiogenic argon is present (Hart and Dodd, 1962). This sample has the low potassium content (0.09 percent K_2O) characteristic of samples for which excess argon has been reported. However, the date obtained does not conclusively show that excess argon is present. A small error in potassium determination would give this same result.

The radiometric dates reported here may be correlated with those obtained by others for basic intrusions in different parts of the Precambrian shield.

The dykes of Set I in the District of Mackenzie may be related to the northeast trending dykes of the Ungava area of northern Quebec (Stevenson, 1963). The dates obtained (Lowdon et al. 1963) are comparable, the oldest falling in the 2400-2700 m.y. range (Figure 16).

The dates given for the differentiated intrusive body at Yellowknife are very near those published for the Nipissing Diabase by Van Schmus et al. (1963), i.e. a minimum value of 1755 m.y. and a probable value of 2170 m.y. for the age of the diabase. There is also a possibility that the Sudbury nickel irruptive may be this old (Fairbairn et al. 1960; Faure et al. 1962).

One of the most important correlations attempted concerns the northwest trending dykes of Set III in the District of Mackenzie and the youngest northwest trending dykes of Ontario. Payne et al. (in press) suggested that the diabase dykes

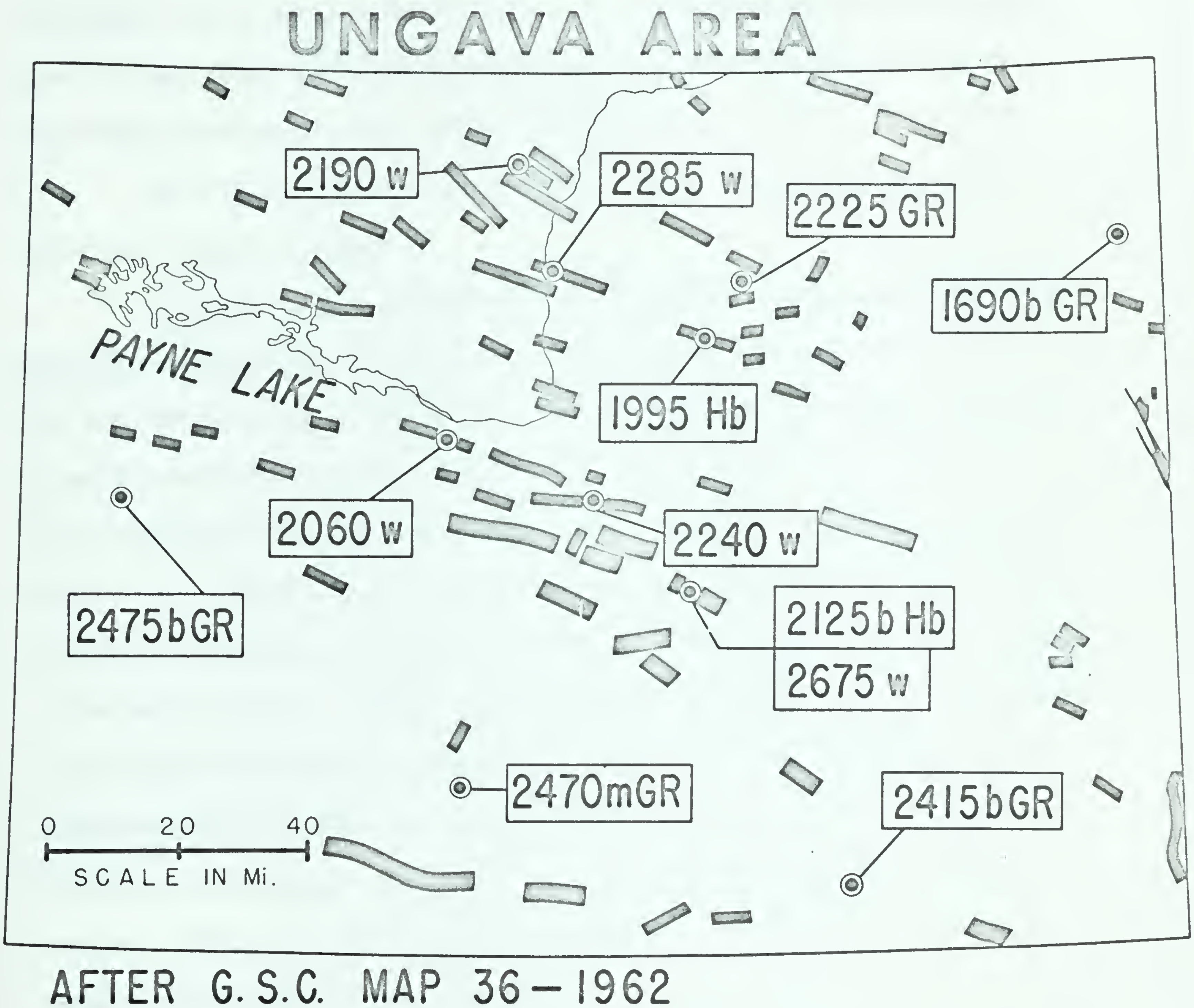


Figure 16. The dykes of the N 70°W swarm in Ungava, giving the same radiometric date as the N 70° - 80°E swarm at Yellowknife.

of these two sets belonged to the same period of intrusion, following the suggestion by Fahrig and Wanless (1963). This idea seems to be confirmed by the dates obtained here: the Ontario samples, taken from Sudbury, Batchawana, Porcupine-Timmins, and the Pigeon River (see Figures 4-7 inclusive, and Porcupine-Timmins map in pocket) give the same dates, within the accepted error, as the Lac de Gras-Point Lake - Coronation Gulf samples of the Northwest Territories (see Figures 1-3 inclusive).

Some other aspects of these radiometric dates are now discussed, using individual cases as examples.

In any given dyke, the centre dyke samples give a lower radiometric date that the contact samples. This is best illustrated by the dyke profile taken across the wide 300 foot dyke striking N 70° - 80°E, north of Prosperous Lake. Figure 17 shows the dates obtained from this profile collected by Drs. R. A. Burwash and F. A. Campbell of the Department of Geology. Most of the coarse-grained centre dyke dates are 300 to 400 m.y. younger than the contact dates, although one 900 m.y. date was obtained. The petrology of most of these samples has been discussed in the previous chapter, where it was suggested that the mineral source of potassium is an important factor: biotite, which retains argon well, is in abundance in the chilled margin of this dyke, but the centre dyke samples must hold their argon in the potassium feldspar of the granophyric intergrowths or the sericitic alteration products. Whatever the cause, more leakage has occurred from the dyke centre rocks than the contact chilled margin rocks.

The differentiated intrusive body at Yellowknife gives three dates (AK 520, AK 463, and AK 497) that are reasonably concordant. Two values (AK 464 and AK 524) are too low. This set of dates indicates that this thick intrusion has been more successful (or more consistent) in retaining argon that the diabase dykes, perhaps because of its size but probably because there was fresh biotite in all the dated samples.

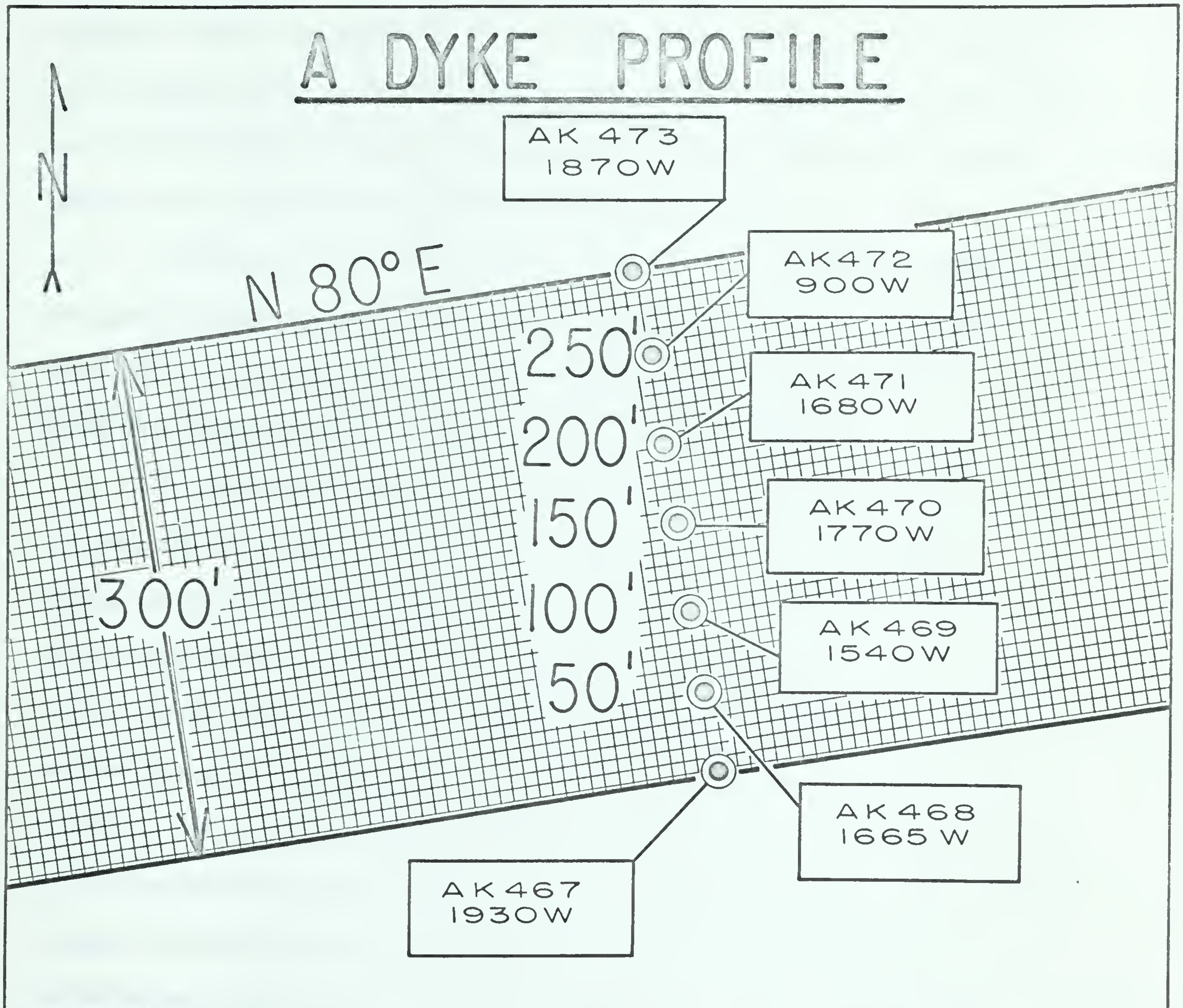


Figure 17. A dyke profile, illustrating the scatter in radiometric dates that may occur in a single dyke.

The N 30° - 60°W set (Set IV) and the N 0° - 30°E set (Set II) at Yellowknife seem to be a conjugate set. If they were intruded at approximately the same time, then the field relations described by Henderson and Brown (1952b) and Wilson (1949) are explained: these investigators found that the dykes of Set II were cut by dykes of Set IV in most cases, but that the opposite relationship is seen in a few places. The age of initial intrusion from this study appears to be from 1800 to 2000 m.y. ago, which is earlier than that proposed by Burwash et al. (1963).

Further work may reveal whether or not there is any significant difference in the ages of intrusion of the differentiated body and the dykes of Set II and Set IV. Many of the dates obtained from the Set I dykes fall in this range, suggesting a possibility of a second intrusion along this east-west trend 1800-2000 m.y. ago.

The dates obtained from the north-trending dykes of Ontario (see Porcupine-Timmins map in pocket) are informative. The oldest date obtained, 1930 m.y., in Keefer township, is believed closest to the initial period of intrusion of this set. In Bristol township, however, field relations show a N 15°W dyke (AK 649) cutting an older N 35°W dyke (AK 648, AK 650) and chilled against it (see sketch, page 21). The western contact of the older dyke gave the oldest date, 1760 m.y. and the western contact of the younger dyke gave a 1500 m.y. date. Sample AK 650 was taken from the centre of the older dyke. Looking at the map of Bristol township, these dykes all appear to belong to the same swarm. Jaeger (1957a, 1957b) showed that a second solidified but incompletely cooled sheet is not likely to form a chilled contact against a first intrusion if the first has not cooled below 300°C. Jaeger's results concern intrusion of a sill or dyke into wet sediments, but the suggestion that a considerable time interval may be involved is more valid for dry environment. The error assigned to the radiometric dates does not permit comment about specific age of intrusion although the dates do fall in the expected sequence, and the question of more than one intrusion along a given trend must be considered again. The centre

dyke sample gives a lower date than the contact sample, as at Prosperous Lake.

Another dyke, possibly of this swarm, was sampled in Taylor township (AK 653) as was a N 70° - 80°E dyke (AK 652) (see sketch, page 22). Both gave nearly the same radiometric date. The interpretation for this is not certain, although the older dyke may have been updated during the intrusion of the younger diabase.

Field relations in Ontario give information conflicting with the idea that all the dykes of a trend are of the same swarm. Campbell (in press) points out one example in the Quemont - Noranda area where a north trending dyke both cuts and is cut by east-west trending dykes. Personal communication with Dr. S. A. Ferguson of the Ontario Department of Mines indicates that along the east boundary of Deloro township (immediately south of Tisdale township), O.D.M. Map 47a is in error, and the north striking dyke cuts the east-west striking diabase. Further, at the same location, a small dikelet strikes east-west and is the latest of the three. In the Porcupine-Timmins area, then, there may be two generations of north trending diabases, or two generations of east-west diabases, or both.

One non-dyke sample taken in the Sudbury area is of interest. It was originally intended to be a sample of the dyke contact, but under closer examination, turned out to be the wall rock. Fine-grained, dark greenish grey, and slightly schistose looking, it does not satisfy descriptions of the Copper Cliff rhyolite mapped in the area (see Figure 5) and under the microscope, was found to be an amphibolite. A photomicrograph of this rock is shown in Plate II, Figure 4. The potassium-argon date obtained from a whole-rock determination was 2420 m.y.

The most consistent body of data was obtained from the northeast striking dyke near Coronation Gulf. The four dates for this dyke, from both whole-rock samples and mineral separates, all fell in the range from 650 m.y. to 700 m.y. and suggest that the age of intrusion was about 675 $\pm$ 20 m.y. ago. This is in general agreement with the ages of 635 m.y. and 640 m.y. given (Leech _et al_. 1963) for

diabase sills intruding the presumed late Precambrian Shaler Group (but not the overlying Paleozoic rocks) near Glenelg Bay on Victoria Island (Christie, 1964). This period of intrusion may have marked the end of Precambrian time in this region. Unfortunately, no radiometric dates are available from the many outcrops of diabase along the coast of the Arctic Ocean, but Christie (1964) considers that the dykes and sills of the Coppermine River, Banks Island, and Victoria Island, and their associated basaltic volcanic formations, belong to a basaltic province that has an areal extent of at least 120,000 square miles.

Because of the absence of scatter in dates caused by tectonic noise, the younger Precambrian basaltic rocks are most amenable to potassium-argon dating. Attempts to find the age of intrusion of younger Phanerozoic rocks have been make successfully: the Triassic Palisades sill (Erikson and Kulp, 1961a, b), the Jurassic dolerites of Tasmania, Antarctica and South Africa (McDougall, 1963b, 1964) and the Mid-Atlantic ridge (Erikson and Kulp, 1961c) show that even very young basic rocks can be usefully dated by the potassium-argon method. Some difficulty was reported by Krueger (1964) in trying to determine the age of "Mohole" basalts.

When it is necessary, then, to attempt to date Precambrian diabase dykes that have been affected by several post-intrusion events, it is important to take an adequate number of samples. In this way, the most suitable can be examined and chosen for the potassium-argon determination. The approach here was almost statistical, but most of these observations could not have been made had single field samples been taken in the various areas, where there was little field evidence for the relative age of intrusion, and no evidence for the magnitude of the time interval involved between periods of intrusion. On the other hand, with fewer determinations, problems would not have been apparent either, and the task of interpretation simpler.

CONCLUSIONS

"There is something fascinating about science. One gets such wholesale returns of conjecture out of such a trifling investment of fact".

Mark Twain, - Life on the Mississippi.

GEOLOGIC INTERPRETATION OF DATA

Gill and L'Esperance (1952) were among the first to compile data on the diabase dykes of the Canadian shield, and to discuss their general character, composition, age and structural relations, and manner of intrusion. Burwash et al. (1963) and Fahrig and Wanless (1963) have more recently discussed the age and tectonic significance of these dykes. A complete consideration of the question of magma source and the tectonic causes underlying dyke intrusion is not within the scope of this study, but a few brief comments are made.

Source and Tectonic Significance

It is generally recognized that primary basalt magmas originate in the upper mantle.

Ringwood (1962) and Green and Ringwood (1963) proposed a model for the crust and upper mantle based on a hypothetical primitive rock type called pyrolite, composed of one part basalt to four parts dunite. Immediately below the Mohorovicic discontinuity, this pyrolite was thought to be represented by dunite and peridotite with minor residual segregations of eclogite, pyroxene granulite, and gabbro. Several possible mineral assemblages are given for this pyrolite, depending on the pressure-temperature conditions: at depths less than 50 kilometers (about 17 kilobars lithostatic pressure) and temperatures in excess of 600-700°C. a plagioclase pyrolite, composed of olivine, pyroxene, and plagioclase was thought to be stable.

Experimental evidence concerning the stability of various mineral phases under mantle and crustal conditions of temperature and pressure, and the possibility

of a single magma yielding the principal basalt magma types is given in the 1963-1964 Carnegie Institute of Washington Yearbook by H. S. Yoder, I. Kushiro, I. Kushiro and H. S. Yoder, and C. E. Tilley and H. S. Yoder.

These experimental studies of various phase equilibria confirmed some of the general concepts of Green and Ringwood (although the term peridotite is preferred to pyrolite) and showed that pressure was the most important variable governing the reactions involved. The genesis of the two principal magma types from one parent magma was shown to be possible, as a result of partial melting and fractionation: both types may be obtained by partial melting of an original peridotitic magma with the composition forsterite - enstatite - diopside (under certain pressure conditions) or by subsequent fractionation of an eclogite derived by partial melting of a garnet peridotite.

In its passage upward from the mantle, then, a magma of peridotitic composition would be subject to a certain decrease in pressure, and the resulting stable assemblance at a depth less than 20 kilometers would most probably be olivine, pyroxene, and plagioclase. The degree of partial melting and fractionation would determine the type (or types) of basalt (or gabbro) produced.

The diabase dykes of this study have been shown to belong to the tholeiitic basalt magma type. The abundance of well-formed plagioclase phenocrysts in chilled contact zones suggest that crystallization had begun before the time of emplacement. The zoning of crystals indicates equilibrium was not achieved in the diabases during the rapid cooling. The mineral assemblages, composed dominantly of pyroxene and plagioclase satisfy expectations based on the experimental results.

If the increase in potassium content in the dykes is real and not imagined, a corresponding decrease in potassium in the source is implied. This raises questions of the degree of mixing or homogeneity of the mantle, the possibility of shallow differentiation reservoirs, and the problem of assimilation of sial by the rising magma.

A tectonic map of the Precambrian shield produced by Stockwell (1962, 1964a, 1964b) is in current use; Stockwell divides the shield into its main structural provinces and suggests the time of major orogenic events (e.g. the Kenoran, Hudsonian and Grenville orogenies). Gill and L'Esperance considered that the dykes were intruded at different times, always in a late stage of an orogenic cycle. Burwash et al. (1963) suggested that episodes of basaltic intrusion followed periods of granitic emplacement during major tectonic events. From this study, however, the periods of intrusion seem to be initiated in between these major events, in a rather random way, throughout Precambrian time. Fahrig and Wanless (1963) suggested that the dykes may have been feeders to surface flows or near surface flows, which have since been eroded, and further attempted to relate the trends of the dyke swarms to the structural trends of the shield.

Some insight into the tectonic significance of the dykes may be gained from the study of fault patterns of the Precambrian rocks. This has been attempted in the western part of the shield by Byers (1962). Operation Overthrust (Parkinson, 1962), begun in Ontario and Quebec, will make possible regional study in eastern shield areas. On a smaller scale the structural relationships of the mafic dykes in the Beartooth mountains of Montana - Wyoming have been analysed by Prinz (1964, 1965). He showed that the trends followed by the Precambrian dykes were the same as the fracture patterns of the Archaean rocks, and that the late Precambrian dolerites had essentially the same trend as the Archaean meta-dolerites.

Periods of Basic Intrusion

The dates obtained from the basic rocks, diabase dykes and sills and one differentiated intrusive body, indicate that there were several periods of basic intrusion throughout the shield during Precambrian time. The major orogenic events of the Precambrian, accompanied by granitic intrusion have been correlated on a continental

and intercontinental scale (see Kulp, 1961). Since the basic intrusive rocks of Precambrian terranes have been dated by both potassium-argon and rubidium-strontium methods in the last few years, it is worthwhile to consider their corresponding correlation.

Nicolaysen et al. (1958), Faure (1963), and Allsopp (1965) reported dates for the Great Dyke of southern Rhodesia, and a few preliminary dates were provided by McElhinny and Opdyke (1964) for the Umkondo and Mashonaland dolerites of southern Rhodesia. Schreiner (1958a) and Nicolaysen et al. (1958) dated the Bushveld complex. McDougall (1963c) discussed dates obtained from Proterozoic dolerites of British Guiana, and Evans and Tarney provided isotopic ages for the Assynt dykes of Scotland. Work is in progress in Western Australia (Andrew Turek, pers. comm.). Schreiner (1958b) reported the age of the Pilansberg dykes of Transvaal, and McDougall (1963a) provided ages from pre-Karroo dykes of South Africa. The ages obtained by these investigators are compiled below in Table 7.

TABLE 7

RADIOMETRIC DATES FROM BASIC PRECAMBRIAN ROCKS OF AFRICA, SOUTH AMERICA, AUSTRALIA, AND THE BRITISH ISLES.

Area	Author	Method	Age m.y.
Africa	Nicolaysen	Rb-Sr	1940
Great Dyke	Faure et al.	Rb-Sr**	2110
	Allsopp	Rb-Sr*	2530
Mashonaland dolerites	McElhinny and Opdyke	K-Ar	1600
Bushveld Complex	Schreiner	Rb-Sr*	1910
	Nicolaysen	Rb-Sr*	1970
British Guiana dolerites	McDougall et al.	K-Ar	2090
		Rb-Sr**	2170
Scotland	Evans and Tarney	K-Ar	2160
Assynt dykes		Rb-Sr**	2190
West Australia Norseman dyke	Turek	K-Ar	2170

Table 7 contd.

Area	Author	Method	Age m.y.
South Africa	Schreiner	K-Ar	1290
	McDougall	K-Ar	1120
			1050
			1030

* half-life of rubidium-87 taken as 5.0×10^{10} years

** half-life of rubidium-87 taken as 4.7×10^{10} years

Comparison with Figure 15 and Table 5 shows that these few dates correspond remarkably well with those obtained from the Canadian basic intrusive rocks.

The potassium-argon results obtained by McDougall from the British Guiana dolerites are the most interesting in comparison with these results because they show the same sort of scatter: six samples, from which pyroxene and plagioclase mineral separates were obtained, showed a spread of 500 m.y. in date. McDougall attributes this to a loss of radiogenic argon by diffusion, explaining that geological evidence suggests that the emplacement of the dolerites was not spread over 500 m.y. Further he suggests that the argon loss occurred at low temperatures, probably below 200° centigrade. As with the Canadian samples, the K-Ar dates do not conclusively indicate several periods of intrusion, although the question is raised.

McDougall also discussed the possibility of strontium leakage, since an isochron plot gave a "true age" of 2170 m.y. if one whole-rock sample was omitted from the plot, but a value of 1850 m.y. if this point is considered.

The same sort of scatter in dates was reported by McElhinny and Opdyke – their three K-Ar ages for the Mashonaland Dolerites ranged from 1430 m.y. to 1640 m.y. while the samples of Umkondo dolerites gave "inconclusive results" and "apparently have suffered loss of argon", and were not reported.

Allsopp, and Evans and Tarney likewise reported ranges in dates of up to

700 m.y. Both K-Ar and Rb-Sr dates showed this scatter.

In general, the K-Ar results and the Rb-Sr results confirmed each other. Although Rb-Sr dates are usually spoken of as "confirming" K-Ar dates, it seems that, as far as basic rocks are concerned, the Rb-Sr dates are not always more consistent or "reliable" than the K-Ar dates.

The possibility of long distance dyke correlation is especially important with respect to its application to the problem of continental drift. If dyke swarms can be correlated for distances from a few hundred to a few thousand miles where there has been no possibility of continental drift, then it is possible to apply the same reasoning to dyke swarms which have been disrupted by continental drift.

Payne et al. (in press) confirmed the Wanless-Fahrig concept that the 1000-1200 m.y. old dykes of Ontario and the Northwest Territories could be considered as a 200 mile long discontinuous intrusion, and applied the same reasoning to the 2200-2400 m.y. old gneisses, schists, and granites, which have been affected by several subsequent events, and show the same geologic character. The present trend of these dyke swarms appears unrelated (Figure 18b) but when plotted on a globe, the Yellowknife and Ungava swarms lie on the same great circle. If Greenland and Scotland are moved along paths determined by physical outline and paleomagnetic findings (and Newfoundland is displaced), then the dyke sets of these areas fall on the continuation of this great circle (Figure 18a). This was presented as "a line of evidence suggesting continental drift".

The ages of the Precambrian dyke swarms are also important and useful in regard to paleomagnetic work, since Precambrian time was of such long duration. The paleomagnetic of the Precambrian dolerites of Rhodesia was discussed by McElhinny and Opdyke (1964) and the significance of this was further commented upon by Gough et al. (1964), who was able to suggest a polar wandering curve relative to Africa for the early Precambrian.

Figure 18a. A reconstruction of Laurasia in Precambrian time: the 2200 m.y. old dykes of Yellowknife, Ungava, and the displaced Greenland, and Scotland fall on one great circle, the 1000 - 1200 m.y. old dykes of Ontario and the Northwest Territories fall on the other.

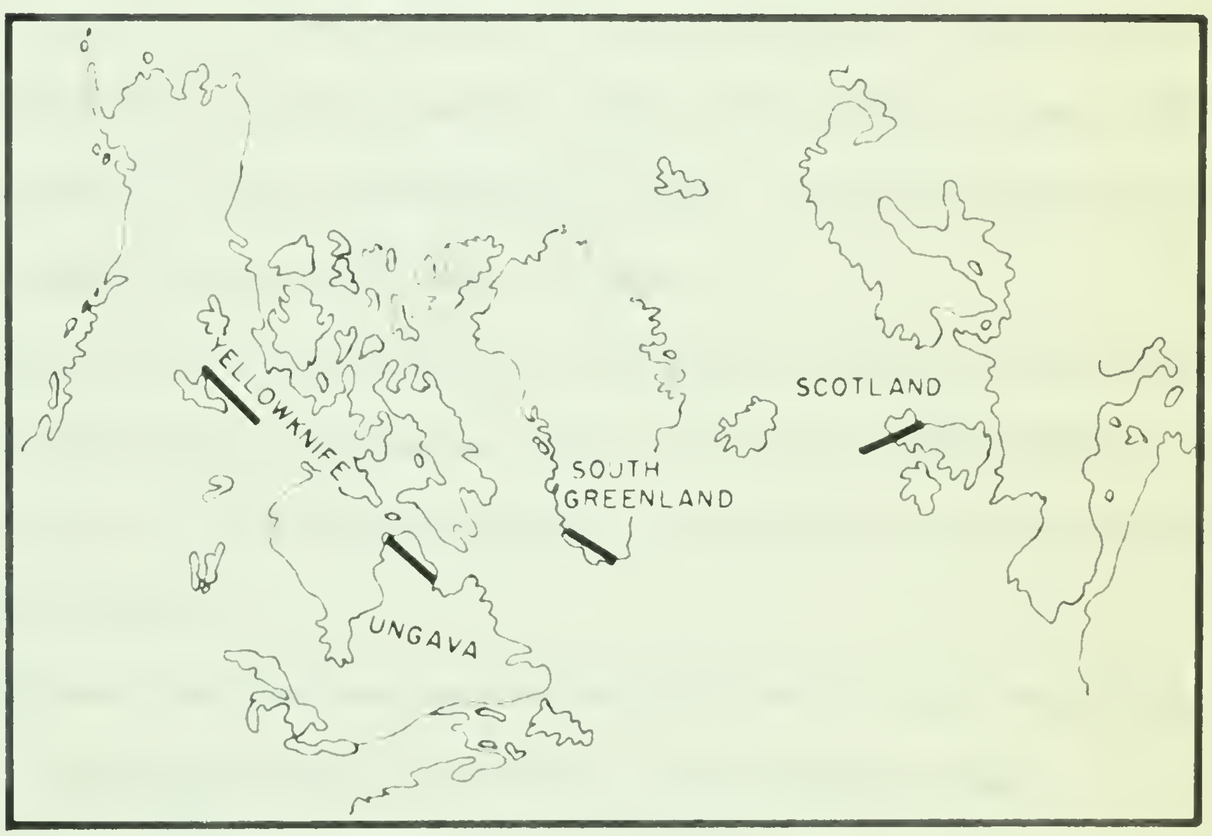


Figure 18b. The present trends of the dyke swarms of Yellowknife, Ungava, Southern Greenland and Scotland.

A paleomagnetic study of the diabase dykes throughout the Canadian shield has been made by Fahrig et al. (in press), in which the paleomagnetic findings are correlated with the potassium-argon radiometric dates.

This type of study need not be confined to the Precambrian dolerites - the Tasmanian dolerites have been studied by Irving (1963) and Stott (1963).

The geologic interpretation and the usefulness of the radiometric dates obtained from basic intrusive rocks depends on the recognition of the age of intrusion. In older Precambrian dykes or sills, which have undergone one or several post-intrusion events, it is difficult to extract this information - the younger rocks are much more satisfactory.

CONCLUSIONS

The major work of this thesis was concerned with potassium-argon radiometric dating. Interpretation of these radiometric dates indicates at least four periods of diabase dyke intrusion in the Precambrian shield, 2200-2400 m.y. ago, 1800-2000 m.y. ago, 1100-1200 m.y. ago, and 600-700 m.y. ago. The differentiated intrusive body was probably intruded 1900-2100 m.y. ago.

The N 70° - 80°E dyke set of the Yellowknife-Prosperous Lake area contained the oldest intrusive rocks dated. They were intruded 2200-2400 m.y. ago, at the same time as a N 70°W set in Ungava. The possibility of two intrusions along this trend still remains.

The dates obtained from the differentiated intrusive body range from 1925-2050 m.y., indicating an event at this time in the Yellowknife area.

Two sets of dykes, trending N 0° - 30°E in the Yellowknife-Prosperous Lake and Lac de Gras areas and N 45° - 60°W in the Yellowknife-Prosperous Lake area only, appear to have been intruded at approximately the same time, 1800-2000 m.y. ago. A north trending set of dykes in Ontario also seems to have been intruded at

this time.

The N 0° - 30°W dyke set of the District of Mackenzie may be traced from the Lac de Gras - Aylmer Lake region to Coronation Gulf, a distance of about 200 miles. This set extends another 100 miles southeast of Lac de Gras, and can be correlated with the N 0° - 30°W dyke set of Ontario, on the basis of age of intrusion, from 1100-1200 m.y. ago.

No definite conclusion can be reached concerning the age of the northeast-trending dykes of Ontario - Quebec: only one date is available, of 1290 m.y. but field evidence suggests that there was more than one period of intrusion along this trend. There was no definite evidence of this sort of "multiple intrusion" along a given trend in the District of Mackenzie.

The youngest dyke dated in this study was the northeast trending dyke at Coronation Gulf. The radiometric dates indicate a probable age of intrusion of 650-700 m.y., at the same time as some of the diabasic rocks of Victoria Island. The basic rocks of this period of intrusion extend over a very large area and represent one of the final events of Precambrian time.

For each dyke set, and for single dykes within a set, the radiometric dates show a scatter effect due to loss of argon. For example, in a single dyke in the Yellowknife - Prosperous Lake area, the range in dates is from 900 to 1925 m.y. This loss of argon represents reflection of major orogenic events in other parts of the shield which have been expressed by local thermal or tectonic events (such as faulting) which have effectively reset the geologic clock. In general, the greatest number of "scatter" dates fall at the times of major orogenic activity in the shield.

The amount of argon leakage may be controlled by which potassium mineral in the rock holds the argon. Biotite is considered the best argon retainer, but the potassium feldspar in sericitic alteration products and in the granophyric intergrowths are also potential sources of argon. Argon would tend to be lost more easily from the

feldspar in the granophric intergrowths, and some would probably be lost during alterations of one mineral to another.

This scatter in dates prevented recognition of multiple intrusions along a given trend from the age data alone.

In choosing whole-rock samples for dating, the dyke contact is recommended. Small flecks of biotite are abundant in the basaltic phases of the chilled margins, but biotite is often scarce in the dyke centres, where granophric intergrowths or sericitic alteration products are the most likely sources of argon. Centre whole-rock samples generally yield a date younger than the contact whole-rock samples. In later Precambrian dykes, of the 1100-1200 m.y. old and the 600-700 m.y. old groups, this effect is not so noticeable. The older the suspected age of an intrusion becomes, the more difficult it is to obtain meaningful whole-rock dates.

The periods of basic intrusion in the Canadian Precambrian shield are very similar to those of other Precambrian terranes of Southern Rhodesia, South Africa, Scotland, New Guinea, and Western Australia.

Analytical and petrologic work supplemented the radiometric dating.

In determining the potassium content for the whole-rock samples, three independent methods were used. The gravimetric results were consistently higher than the results obtained from flame photometric or x-ray - fluorescence techniques in the range 0.0 to 1.0 percent K_20. The x-ray - fluorescence values were not acceptable for amounts of K_20 greater than 1.5 percent. The value used in dating calculations was chosen after consideration of these and other salient facts.

The older dykes, when considered together, seem to have a lower average potassium content than the younger dykes.

Determination of sodium and silica as well as potassium made possible the classification of the diabase dykes as tholeiitic basalt, by use of a total alkali-silica

diagram. Individual samples appeared to lie in the alkali-olivine basalt field, but collectively, the dykes in any given set were tholeiitic in nature.

The differentiated intrusion is very similar to the Basistoppen sheet, intrusive into the Skaergaard intrusion of eastern Greenland. The basal picrite zone at Yellowknife was probably formed by settling of early-formed olivine crystals, during the cooling and fractionation of the complex. More work is required to determine whether or not the upper quartz gabbro of the Yellowknife intrusion consists of several zones, as does the Greenland intrusion.

In general, the basic rocks studied here were very similar to other basic rocks of all ages and all places of the world.

As final advice for anyone contemplating a similar geochronologic study in the future, the following conditions are recommended:

(1) The samples taken from a particular dyke or sill should be plentiful. In this way, some choice is available in selecting dating material, and in case of disaster, a "statistical" approach may be made, as in this study.

(2) If possible, the area chosen should be one where there has been little tectonic "noise": as far as Precambrian basic intrusive rocks are concerned, the older they are, the more difficult the discovery of age of intrusion. This idea is expressed in the following series of hypotheses:

Age is still a Basic Problem - the older the age, the greater the problem.

Time intensifies the Basic Problem - were there one or a dozen intrusions, and <u>when</u>?

Old age complicates dating. As older rocks begin to lose their memory, their ages blur with time.

The age of basic intrusion is inversely proportional to its ease of discovery.

From which one might derive Leech's Law "Updating and uplifting have the same effect; old dykes and old ladies give young ages".

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APPENDIX A

SAMPLE LOCATIONS

The following is a list of all the samples used in this study. Samples listed with a specimen number beginning with RAB, REF, or SF were not collected by the writer. Samples without AK numbers are at the end of the list.

SAMPLES

AK No.	Specimen No.	Trend	Location
123	RAB 3782a	-	From granite at contact of dyke, west of Kam Lake; 62° 26'N, 114° 24'W; G.S.C. Map 48-17A.
261	RAB 3777	N 70°E	From 100 ft. wide diabase dyke, west end of small lake south of Baptiste Lake; 62° 41'N, 114° 11'W; G.S.C. Map 868A.
439	RAB 3783	N 30°E	From diabase dyke west of Kam Lake; 62° 26'N, 114° 24'W; G.S.C. Map 48-17A. (Same location as AK 123).
440	RAB 3788b	E - W	From contact of diabase dyke, Redout Lake Area; 62° 47'N, 113° 03'W; G.S.C. Map 1024A.
441	REF A-89'48	N 10°E	From diabase dyke cut by northwest trending dyke, Matthews Lake area; 64° 06'N, 111° 21'W; G.S.C. Map 1024A.
442	REF A-17'48	E - W	From centre of 150 ft. wide diabase dyke, Matthews Lake area; 64° 01'N, 111° 10 1/2'W; G.S.C. Map 1024A.
443	RAB 3788a	EW	From contact of diabase dyke Redout Lake area; 62° 47'N, 113° 03'W; G.S.C. Map 645A. (Same dyke as AK 440).
444	REF C-13'48	N 40°W	From contact of diabase dyke, Matthews Lake area; 64°00 1/4'N, 111°06'W; G.S.C. Map 1024A.
445	REF A-29'48	N 25°W	From centre of 85 ft. wide dyke cutting north trending dyke, Matthews Lake area; 64°04 1/2'N, 111°18 1/2'W; G.S.C. Map 1024A.

AK No.	Specimen No.	Trend	Location
446	RAB 3778	-	From granite near contact of 20 in. cyke trending N 70°E, 60 ft. south of 100 ft. N 70°E dyke (AK 261), west end of small lake south of Baptiste Lake; 62°41' N, 114°11'W; G.S.C. Map 868A.
447	REF F-87'47	E - W	From 250 ft. wide diabase dyke, Matthews Lake area; 64°06'N, 111°16'W; G.S.C. Map 1024A. Sample 20 ft. from contact.
448	REF D-4'48	N 25°W	160 ft. wide dyke, Matthews Lake area; 64°04'N, 111°11'W; G.S.C. Map 1024A. Sample 30 ft. from contact.
449	REF A-121'48	N	From diabase dyke, Matthews Lake area; 64°05 1/2'N, 111°15 1/2'W; G.S.C. Map 1024A.
450	RAB 3777	N 70°E	From same sample and location as AK 261. (See AK 261, AK 446).
452	REF I-13'47 (1882)	-	From contact of 220 ft. N 10°W trending dyke, in area of injection gneiss, Lac de Gras area; 64° 46'N, 11° 54'W; G.S.C. Map 977A.
453	REF F-87	E - W	From same location as AK 447.
463	REF P-29'39	-	From ultrabasic layer of differentiated intrusive north of Hay Lake; 62°28 1/2'N, 114°15'W; G.S.C. Map 709A.
464	REF BG-116	-	From gabbroic layer of differentiated intrusive north shore of Duck Lake; 62° 26'N, 114°14'W; G.S.C. Map 709A.
465	RAB 4975	N 30°E	From chilled margin of dyke west of Kam Lake; 62°26'N, 114°24'W; G.S.C. Map 48-17A. (Same location and dyke as AK 439).
466	RAB 4977	N 70°E	From chilled margin of same dyke as AK 450.
467	RAB 4980a	N 80°E	From chilled margin at south contact of 300 ft. dyke, Prosperous Lake North; 62°42'N, 114°12'W; G.S.C. Map 868A.
468	RAB 4980b	N 80°E	From 50 ft. north of south contact (Same dyke as AK 467).

AK No.	Specimen No.	Trend	Location
469	RAB 4980c	N 80°E	From 100 ft. north of south contact.
470	RAB 4980d	N 80°E	From 150 ft. north of south contact.
471	RAB 4980e	N 80°E	From 200 ft. north of south contact.
472	RAB 4980f	N 80°E	From 250 ft. north of south contact.
473	RAB 4980g	N 80°E	From 300 ft. north of south contact, at chilled north margin of dyke.
474	RAB 4981	N 10°E	From 9 in. dyke cutting 300 ft. N 80°E dyke (AK 467-473), Prosperous Lake North; 62°42'N; 114°12'W; G.S.C. Map 868A.
497	DL-23	-	From biotite rich hornfels derived from greywacke baked by ultrabasic intrusive, on east side of outcrop on the north shore of Duck Lake; 62° 26'N, 114° 14'W: G.S.C. Map 709A.
499	DL-23	-	From same sample and location as AK 497.
513	REF I-43'47	N 30°W	From centre of 300 ft. wide dyke, Lac de Gras area; 64° 57'N, 110° 13'W; G.S.C. Map 977A.
514	REF F-86a'47	E - W	From diabase, Lac de Gras area; 64° 50'N, 110°40'W; G.S.C. Map 977A.
515	REF F-72'63	N 70°E	From north contact of 300 ft. dyke, north shore of Long Lake; 62°25 1/2'N, 114° 27'W: G.S.C. Map 709A.
518	D-1	E - W	From centre of 24 ft. dyke, on island west of Post Island; 62°17'N, 114°17'W; G.S.C. Map 709A.
519	REF J-14'47	N	From contact of 115 ft. wide dyke, Lac de Gras; 64°50'N, 110°35'W; G.S.C. Map 977A.
520	Core C-158		From ultrabasic differentiate of sill, 158 ft. from surface, at drill site; Ptarmigan Road, Yellowknife; 62°30'N, 114°16 1/2'W; G.S.C. Map 868A.
523	REF F-74'63	N 50°W	From south contact of 150 ft. wide dyke, north shore of Long Lake; 62°28'N, 114° 27 1/4'W; G.S.C. Map 709A.

AK No.	Specimen No.	Trend	Location
524	UB-18	-	From olivine gabbro on small island north of Ruth Island; 62°18'N, 114°14 1/2'W; G.S.C. Map 709A.
525	REF F-76'63	N	From east contact of dyke, north shore of Long Lake; 62°28'N, 114° 25 1/2'W; G.S.C. Map 709A.
527	REF F-8'63	N 20°W	From dyke south of Prelude Lake;62° 34'N, 114°02'W, G.S.C. Map 709A (Sample 10' from margin of lake).
528	REF F-1'63	-	From altered gabbro, 114 ft. south of bridge across Yellowknife River; 62° 31'N, 114°19'W; G.S.C. Map 868A.
530	REF F-71'63	-	From metadiorite at 2000 ft. level, Giant Mine, Yellowknife, G.S.C. Map 868A.
531	REF F-74'63	-	From granite at contact with N 50°W trending dyke, north shore of Long Lake; 62°28 1/2'N, 114°27 1/2'W; G.S.C. Map 709A (Same dyke as AK 523).
536	REF F-73'63	N 70°E	From centre of 300 ft. dyke north shore of Long Lake; 62°28 1/2'N, 114°27'W; G.S.C. Map 709A (Same dyke as AK 515).
537	REF F-75'63	N 50°W	From centre of 150 ft. dyke, north shore of Long Lake; 62°28 1/2'N, 114°27'W; G.S.C. Map 709A (Same dyke as AK 523).
574	AVP-1	N 50°W	From southwest chilled margin of dyke ("Con 4" dyke) on north side of road opposite turn-off to mine shaft, Con-Rycon Camp, Yellowknife; 62°26 1/2'N, 114° 21'W; G.S.C. Map 709A.
575	AVP-2	N 60°W	From 45 ft. away from southwest contact of "Con 4" dyke, near the same location as AK 574.
576	AVP-3	N 50°W	From southwest contact of 150 ft. dyke, south shore of Long Lake; 62°28 1/2'N, 114°26'W; G.S.C. Map 709A.
577	AVP-3	-	From granite at contact with 150 ft. dyke; same sample and location as AK 576.
578	AVP-4	N 50°W	From centre of 150 ft. dyke, 70 ft. from southwest contact; 62°28 1/2'N, 114° 26'W; G.S.C. Map 709A (Same dyke as AVP 3).

AK No.	Specimen No.	Trend	Location
579	AVP-5	N 70°E	From north contact of 315 ft. dyke, west of Yellowknife airport; 62°28'N, 114°31'W; G.S.C. Map 709A (Sample is from the north dyke of the parallel pair mapped).
580	AVP-10	-	From granite at contact of dyke east of Ryan Lake; 62°35 1/2'N, 114°31'W. (G.S.C. Map 709A).
581	AVP-6	N 15°E	From composite 1 ft. wide dyke cutting major 315 ft. dyke (See AK 579) west of Yellowknife airport; 62°28'N, 114°31'W; G.S.C. Map 709A.
582	AVP-7	N 70°E	From centre of dyke, 95 ft. from north contact of 315 ft. dyke, west of Yellowknife airport; 62°28'N, 114°31'W; G.S.C. Map 709A. (Same dyke as AK 579).
583	AVP-8	N 75°E	From small 4 in. dyke 200 ft. south of 315 ft. dyke west of Yellowknife airport, (see AK 579, AK 582); 62° 28'N, 114° 31'W; G.S.C. Map 709A.
584	AVP-10	N 70°E	From north contact of dyke in contact with granite; same sample and location as AK 580.
585	CON 4 UG	N 50°W	From centre of dyke ("Con 4" dyke) on 2300 level, Con-Rycon Mine, Yellowknife, (See AK 574, AK 575).
586	AVP-11	N 70°E	From south contact of dyke in contact with volcanics, east of Ryan Lake; 62° 36'N, 114°21 1/2'W; G.S.C. Map 868A. (Dyke is northernmost dyke of pair mapped).
587	AVP-12	N 70°E	From offshoot of dyke, east of Ryan Lake; 62°36'N, 114°21 1/2'W; G.S.C. Map 868A (Same dyke as AK 586).
588	AVP-13	N 70° E	From 60 ft. north of south contact of dyke, east of Ryan Lake; 62°36'N, 114° 21 1/2'W; G.S.C. Map 868A (Same dyke as AK 586, AK 587).
589	CON 4 UG	N 50°W	From contact of dyke ("Con 4" dyke) 2300 level, Con-Rycon Mine, Yellowknife (see AK 585).

AK No.	Specimen No.	Trend	Location
590	REF R-1'65	N 40°W	From chilled margin of 18 ft. dyke, west of Yellowknife Bay, N.W.T.; 62° 29'N 114°21 1/2'W: G.S.C. Map 709A.
591	REF R-2'65	N 26°W	From chilled margin of 3 ft. dyke, northwest of conglomerate outcrop on Giant Mine Property, Yellowknife; 62°30'N, 114°20'W; G.S.C. Map 868A.
592	REF R-3'65	N 30°W	From edge of 15 ft. dyke, 300 ft. north of AK 591.
593	REF R-4'65	N 35°W	From edge of 12 ft. dyke, cut by a 6 in. composite stringer with the same strike (north of AK 591, AK 592); 62°30'N, 114°20'W; G.S.C. Map 868A.
594	REF R-7'65	N 45°W	From edge of 5 ft. dyke on winter tractor road, east of Yellowknife Bay; 62°30'N, 114°18'W; G.S.C. Map 709A.
595	REF R-10A'65	N 20°E	From centre of 60 ft. wide dyke at waters edge, east shore of Prosperous Lake; 62°35 1/2'N, 114° 11'W; G.S.C. Map 868A.
596	REF R-10B'65	N 20°E	From edge of same dyke as AK 595.
597	Pt. Lk. 1	N 20°W	From west contact of 150 ft. dyke, northeast arm of Point Lake; 62°20'N, 113°00'W; G.S.C. Map 18-1960.
598	Pt. Lk. 2	N 20°W	From east contact of same dyke as AK 597.
599	CG-1	N 10°E	From centre of 120 ft. wide dyke, east side of lake, 8 miles south of Coronation Gulf and 8 miles east of the Tree River; 67°31'N, 111°33'W; G.S.C. Map 45-1963.
600	CG-2	N 10°E	From contact of same dyke as AK 599.
601	CG-3	N 30°E	From biotite granite at east contact of 200 ft. dyke located 8 miles south of Coronation Gulf and 8 miles east of the Tree River; 67°31'N, 111°33'W; G.S.C. Map 45-1963.
602	CG-3	N 30°E	From east dyke contact, same sample and location as AK 601.

AK No.	Specimen No.	Trend	Location
603	CG-4	N 30°E	From porphyritic phase of dyke centre, 20 ft. from west contact, (Same dyke as AK 601 AK 602).
604	CG-5	N 35°-40°W	From contact of 160 ft. wide dyke, southwest of unnamed lake located 8 miles south of Coronation Gulf and 8 miles east of the Tree River; 67°31'N, 111°33'W; G.S.C. Map 45-1963.
605	CG-6	N 35°-40°W	From centre of same dyke as AK 604.
606	CG-7	N 30°E	From northwest contact of dyke cutting northwest trending dykes (AK 604, AK 605), southwest of unnamed lake, 8 miles south of Coronation Gulf and 8 miles east of the Tree River; 67°31'N, 111°33'W; G.S.C. Map 45-1963.
607	0-13	N 30°W	From west contact of 20 ft. dyke, 135 ft. northeast of Middle Falls, Pigeon River; 48°00'N, 89°45'W; O.D.M. Prelim. Map P-177.
608	CG-8	N 30°E	From centre of same dyke as AK 606.
609	CG-9	N 60°W	From centre of 100 ft. wide dyke, northwest of unnamed lake, 8 miles south of Coronation Gulf and 8 miles east of the Tree River; 67°31'N, 111°33'W; G.S.C. Map 45-1963.
610	CG-10	N 60°W	From contact of same dyke as AK 609.
611	0-14	N 30°W	From edge of dyke forming lip of Middle Falls, Pigeon River; 48°00'N, 89°45'W; O.D.M. Prelim. Map P-177.
612	0-15	-	From chilled margin of 4 ft. sill cut by diabase dykes (AK 607, AK 611), Pigeon River; 48°00'N, 89°45'W; C.D.M. Prelim. Map, P-177.
613	CG-12	N 30°W	From contact of 60 ft. wide dyke north of unnamed lake, 8 miles south of Coronation Gulf and 8 miles east of the Tree River; 67°31'N, 111°33'W; G.S.C. Map 45-1963.
614	CG-13	N 30°W	From centre of same dyke as AK 613.

AK No.	Specimen No.	Trend	Location
615	0-16	N 30°W	From west contact of coarse-grained dyke, 235 ft. northeast of Middle Falls, Pigeon River; 48°00'N, 89°45'W; O.D.M. Prelim. Map P-177.
616	0-1	N 60°W	From centre of dyke crossing Frood Road, Sudbury; 46°30'N, 81°00'W; Lot 6, Concession 5, McKim Township, Ontario; O.D.M. Map 1956-1. Sample 50 ft. from northeast contact.
617	0-2	-	From country rock 2 ft. from contact with northwest trending dyke described as AK 616.
619	0-4	-	From chilled phase of sill east of Nairn, outcropping south of the Trans Canada Highway; 46°15'N, 81°35'W: G.S.C. Map 1063A.
620	0-5	N 40°W	From southwest contact of 65 ft. wide dyke at the Chippewa Falls, Harmony River; 46°57 1/2'N, 84° 25'W; O.D.M. Map 35b. Sample 6 in. from contact.
621	0-6	N 40°W	7 in. from contact of same dyke as AK 620.
622	0-7	N 40°W	1 ft. from contact of same dyke as AK 620, AK 621.
624	0-7	N 55°W	From southeast edge of dyke forming lip of High Falls, Pigeon River; 48°00'N, 89°40'W; O.D.M. Prelim. Map P-177.
647	SF 1a	N 20°W	From west contact of 30 ft. dyke, north side of Highway 101, Keefer Township; 48°18'N, 81°45'W; O.D.M. Map 47d.
648	SF 3b	N 35°W	From west contact of older diabase dyke, outcropping in Redsucker River, Bristol Township; 48°23'N; 81°30'W; O.D.M. Map 1957-7.
649	SF 3cA	N 15°W	From west contact of diabase dyke cutting N 35°W dyke (AK 648), outcrop in Redsucker River, Bristol Township; 48°23'N, 81°30'W; O.D.M. Map 1957-7.
650	SF 3cB	N 35°W	Same location as AK 649; same dyke as AK 648 (centre dyke sample).

AK No.	Specimen No.	Trend	Location
651	SF 4b	N 50°W	From contact of dyke, north side of quarry on Highway 101, between Schumacher and South Porcupine, Tisdale township; 48°28'N, 81°14'N; O.D.M. Map 47a.
652	SF 5	N 60°-80°E	From chilled phase of 500 ft. dyke outcropping along highway, south half of Taylor township; 48°35'N, 80°37 1/2'W; O.D.M. Prelim. Map P-119.
653	SF 5Ab	N	From narrow dyke cut by N 60°-80°E dyke; same location as AK 652.
-	BG-1'47	-	From gabbroic layer of differentiated intrusive east of drill site; 62°30 1/2'N, 114°16'W; G.S.C. Map 868A.
-	BG-2'47	-	From ultrabasic layer of differentiated intrusive exposed as cliff face west of drill site; 62°30 1/2'N; 114°16 1/3'W; G.S.C. Map 868A.
-	UBS	-	From serpentine in lower, ultrabasic layer of differentiated intrusive east of Yellowknife Bay; 62°30 1/2'N, 114°16 1/2'W; G.S.C. Map 868A.
-	C-30	-	From same core as AK 520, 30 ft. from surface.
-	G-15	-	From gabbroic layer of differentiated sill east of drill site, Ptarmigan Road, Yellowknife; 62°30 1/2'N, 114°16'W; G.S.C. Map 868A.
-	DL-2	-	From contact of upper part of differentiated sill and greywacke, north shore of Duck Lake; 62°26 1/2'N, 114°14 1/2'W; G.S.C. Map 709A.
-	DL-27	-	From gabbro of sill at contact with baked greywacke, same location as AK 497.

APPENDIX B

ANALYTICAL METHODS

Sample Preparation

Unweathered and, so far as possible, unaltered dyke material was chosen. Samples were sawn from hand specimens taken right at the contact with the country rock (where available). Thin slices parallel to the contact were cut at a distance of 1 to 3 centimetres from the contact. Samples were ground by hand using a pestle and mortar or by using a pulverizer (a Willy- Bleuler Swing-mill for one minute) and sieved.

The mesh size chosen for potassium-argon work was from 45 to 120 mesh. In most cases, material of either the 45 to 60 mesh or the 60 to 120 mesh interval was used, but when only a small amount of sample was available, both size fractions were combined Splits of the same material were used for the argon extraction and all three methods of potassium analysis. The split chosen for x-ray fluorescence work was reground to less than 325 mesh in size (one minute in the Willy-Bleuler Swing-mill).

Potassium Determination

Gravimetric Method:

The K_2O content of the diabase dykes was expected to average 0.8 to 0.9 percent, with a range from zero to two percent. To obtain an optimum amount of precipitate (or at least 150 milligrams), the initial sample weight chosen was one gram. In Samples with a very low potassium content, this was not sufficient, but some difficulty would have resulted from trying to quantitatively analyse larger amounts of material.

The method used involved decomposition of the sample by heating with hydrofluoric and sulphuric acids, and removal of the excess of these acids by evapor-

ation and ignition. The potassium was removed by leaching the residue with hot water and precipitated from the resulting neutral sulphate solution with sodium tetraphenol borate. This "neutral leach" method was described by Abbey and Maxwell (1960), although Wittig and Raff (1951) proposed tetraphenol boron precipitation.

Flame Photometric Method:

Decomposition, evaporation, ignition, and leaching of the sample was as given above. The following modifications of this general method were made :

1. 0.25 gram of sample was weighed initially, and
2. After one leaching (i.e. one complete cycle of leaching), the sample was transferred to the filter paper and rinsed with hot distilled water. The filtrate was then transferred into a 100 ml. volumetric flask, cooled and made up to volume.

A perkin Elmer Flame Photometer was used for the determinations of the alkalis. Since the sodium content of the samples was determined using the same sample solution prepared for potassium determination, standards were prepared containing both sodium and potassium. In addition, a single leach rather than a double leach was made on the assumption that magnesium was present in the sample in some quantity: in this case, ten percent magnesium oxide was assumed. Therefore, a series of neutral standard solutions were made, containing 0, 10, 20... 100 parts-per-million (ppm.) Na_20 and K_20 and 7.5 ppm. $MgS0_4$.

The instrument was calibrated using these standards after peak positions were ascertained using pure sodium and potassium solutions. Initial calibration was made with the 50 ppm. and the 100 ppm. standards, and each sample was "bracketed" by the appropriate standard solutions. Two separate sets of readings were made for each sample group, and the average of these two readings was used in calculation.

X-ray Fluorescence Method:

All the samples were briquetted in an Applied Research Laboratories Inc. Briquetting Machine Type 4451. About 1.5 cu. cc. powder (finer than 325 mesh) was put in each briquette, and backed with cellulose powder. The pressure was applied slowly (at a rate of 2,000 psi. every 15 seconds) until 10,000 psi. were reached, held at this pressure for 30 seconds, then raised to 15,000 psi. and held for 60 seconds. The pressure was released slowly.

Four samples were mounted together in the sample holder of Norelco x-ray equipment (basic unit type 12215/0). A chromium tube was used, energized at 50 kilovolts and 40 milliamps, and an E.D.D.T. analysing crystal. The flow proportional counter, operating at 1540 volts, was supplied with a 90% methane - 10% argon gas mixture. A vacuum of 0.2 to 0.5 mm. mercury was maintained in the x-ray tube. A fixed time for counting (10 seconds) was preferred, and the pulse height analyser was used to limit interference.

The above conditions were maintained throughout all the potassium runs. However, the samples were run on three separate occasions, and the positions of the potassium peak and the background peak (both measured in degrees 2θ) changed slightly from day to day, as did the level voltage and width voltage of the pulse height analyser.

The diabase W-1 was used as a running standard throughout: it was repeated with every group of three unknowns. The counts-per-second for W-1 and the three unknowns are recorded, then the background counts-per-second, and finally repeat values for the four samples. The average counts-per-second of the two separate potassium peak runs was taken for a final value, and background counts-per-second were subtracted. The percentage of K_2O in W-1 was taken to be 0.62 (Goldich and Oslund, 1956) and, using the mean value for all the W-1 determinations, a factor was obtained converting counts-per-second of the unknowns to percent K_2O. The

statistical standard deviation (Spiegel, 1961) in W-1 determinations was ± 2.0 percent (at the 68.3 confidence level).

Sodium Determination

Flame Photometric Method:

Sodium was determined in conjunction with the flame photometric determination of potassium, from the same solution prepared as described above, and by the same method.

Silica Determination

X-ray Fluorescence Method:

The briquettes made for the potassium determinations were used for the silica determinations. The same general conditions apply with respect to equipment, tube, analysing crystal, etc. A similar method of running the samples was used, although the standard deviation of W-1 in this case was ± 1.0 percent.

Determination of Radiogenic Argon

Argon Extraction:

The argon extraction system used was a flux-fusion system the same in principle as that described by Goldich *et al*. (1961). The construction of the train closely followed the "early argon extraction system" described by Goldich *et al*. (1961). The changes made involved the use of glass breakseals and joins rather than mercury cutoffs, and the substitution of a second cold trap for the magnesium perchlorate trap. A titanium getter was used.

The extraction, purification and collection of the argon was accomplished in much the same way as described by Goldich *et al*. (1961), and the accompanying copy (Figure B-1) of the data sheet used during a run outlines the various steps.

Department of Geology, Geochemistry
University of Alberta

POTASSIUM-ARGON

Run No. 636 AK No. 602 Description: Whole rock dyke

Contact of CG - 3 45 - 60 mesh

Sample Wt. 3.0838 gm. South of Coronation Gulf

67°31'N, 111°35'W

Spike No. A - 500

I Preparation

☑ Flux (10 × Sample Wt.) ☑ Getter ☑ Leak testing

☑ Sample (+ filter) ☑ Steel Balls ☑ Pumps

☑ Spike ☑ C-trap ☑ Heaters

Outgassing 12 hrs. Torching: 5 - 10 minutes around sample

II Fusion

☑ Cool flux ☑ Drop sample ☑ Introduce Spike Argon

☑ Seal F-train ☑ Start fusion (65v) ☑ Trap H_2O

III Transfer

☑ H_2O trapped with liq. N_2 ☑ Break seal ☑ Seal off P-train

☑ Seal off from pumps ☑ Short cleanup to TG_1= 97 ☑ Heat C-trap

☑ Drop furnaces from Ni-crucible & $Mg(ClO_4)_2$ ☑ Liq. N_2 on C-trap, 30 min. Tg 190

IV Purification

☑ Preliminary cleanup to TG_1= 45 ☐ W-filament on .... hr.

☑ Gettered 2 min. hrs. to TG_1= 190 ☑ Sample trapped out 20 minutes Tg 190

V Notes

Fusion - 12. 15 p.m. - powerstat to 65v.

1. 15 p.m. - powerstat to 85v.

CuO trap changed

4. 00 p.m. - off

Melt - very good. No obstruction in furnace.

FIGURE B - 1

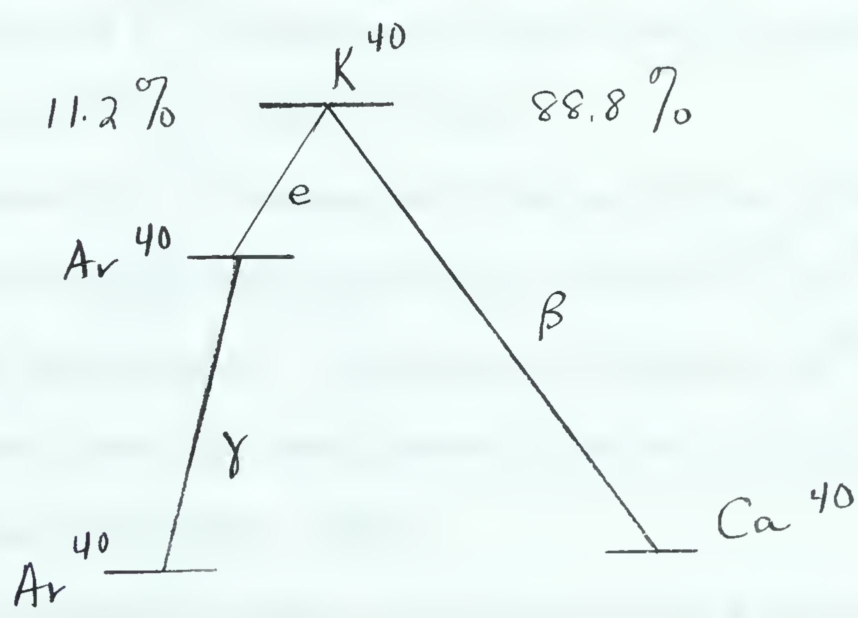
Measurement of Isotope Ratios:

Discussion of the preparation of Ar^{38} spikes and their calibration have been presented by Goldich et al. (1961), and is not given here. The spikes used were prepared and calibrated by Dr. H. Baadsgaard of the Department of Geology, University of Alberta, Edmonton.

The mass spectrometer used was a 60 degree Nier-type. Most of the samples were analysed under dynamic conditions, although mineral samples and small whole-rock samples were run under static conditions. Calibration runs on atmospheric argon were made to determine mass discrimination effects. Only a few runs were made by the author: the majority were done through the kindness of Drs. Baadsgaard and Cumming of the Departments of Geology and Physics, respectively.

Computation of t from Ar^{40}-K^{40} measurements:

The potassium-argon method of determining the age of a mineral depends on the decay of K^{40} to Ar^{40} (by K-capture and subsequent γ -radiation). K^{40} also decays by B - emission to Ca^{40}. This may be shown diagramatically as follows:



Ar^{40} accumulates in potassium-rich minerals at a rate depending on two constants, λ_e, the K-capture decay constant, and λ_β, the beta decay constant. The constants used here are:

$$\lambda_e = 5.89 \times 10^{-11}/\text{year},$$

and

$$\lambda_\beta = 4.76 \times 10^{-10}/\text{year},$$

giving a total decay constant of:

$$\lambda = 5.349 \times 10^{-10}/\text{year}.$$

The relative abundance of K^{40} is

$$K^{40}/K = 0.0118 \text{ atomic percent.}$$

The equation used to calculate the Ar^{40}/K^{40} date, (or the "radiometric age") of a rock or mineral is:

$$t = \frac{1}{\lambda_e + \lambda_\beta} \ln \; 1 - \frac{Ar^{40}}{K^{40}} \quad \frac{(\lambda_e + \lambda_\beta)}{\lambda_e}$$

which becomes, on substitution of the proper constants and conversion to common logarithms,

$$t = 4.307 \times 10^9 \log \left[1 - \frac{Ar^{40}}{K^{40}} \; (9.07) \right] \text{ years}$$

The amount of K^{40} is obtained as follows from the percent K_2O:

$$\text{ppm } K^{40} = 1.0028 \times \% \; K_2O$$

The amount of Ar^{40} is measured by isotope dilution: a known amount of (spike) Ar^{38} is added to the sample during extraction, and the Ar^{38}/Ar^{40} is obtained from the mass spectrometer measurements. The amount of radiogenic Ar^{40} is computed after a series of corrections have been made for residual argon, spike argon, and mass discrimination effects (see Shafiquillah, 1963).

Mass discrimination effects were determined by dynamic mass spectrometer runs using standard air argon. The mass discrimination was obtained by measuring Ar^{40}/Ar^{36} and comparing it to the standard value (295.5).

A sample calculation is given as illustration in Figure B-2.

RUN 636 AK 602 K_2O = 0.81%

WHOLE ROCK DYKE

Sample - 3.0838 gm.

Spike - A-500 - 0.9484×10^4 cc. STP Ar^{38}

% radiogenic Ar^{40} = 98.8

DYNAMIC

		residual		mass discrimination factor		air		spike	
40	$3.44 \times 1000 = 3440$	$- \underline{22}$	$= 3418$	$\times \underline{1.000}$	$=$	$(\underline{38.4}$	$+$	$\underline{16.4})$	$= 3363.2$
38	$4.68 \times 1000 = 4680$	$- \underline{5.7}$	$= 4674.3$	$\times \underline{1.003}$	$= 4688.3$		$-$	$\underline{x}$	
36	$.45 \times 3 = 1.35$	$- \underline{0.72}$	$= 0.63$	$\times \underline{1.006}$	$= 0.63$		$-$	spike $(\underline{0.5})$	$= 0.13$ (295.5)

Ar^{36}/Ar^{38} spike = 0.0001

Ar^{40}/Ar^{38} spike = 0.0035

$$\frac{Ar^{38}}{Ar^{40}} = 1.3940$$

$$Ar^{40}/gm. = \frac{0.9484 \times 10^{-4}}{3.0838 \times 1.3940} = 0.2206 \times 10^{-4}$$

$$ppm.\ Ar^{40} = 0.2206 \times 10^{-4} \times 1.7846 \times 10^{3} = 0.03937$$

$$ppm.\ K^{40} = 0.812$$

$$\frac{Ar^{40}}{K^{40}} = 0.0485$$

$$t = 4.307 \times 10^{9} \log (1 + 0.04849 (9.07) = 682 \text{ m.y.}$$

Figure B-2

APPENDIX C

ANALYTICAL RESULTS

K_2O and Na_2O Content in Basic Dykes and Sills

Sample	*x-r-f %		*KTPB %	*Flame %	Best K_2O %	Na_2O %
N 70° - 80° Trend, Yellowknife - Lac de Gras Areas (Set I)						
AK 579	0.53	0.54	0.64	0.60	0.57	2.02
AK 581	0.06	0.08	-	0.06	0.07	1.90
AK 582	0.77	0.78	0.93	0.81	0.81	2.29
AK 583	2.08	1.63	1.93	1.93	1.93	2.13
AK 584	2.30	1.72	2.02, 2.00	2.11	2.02	2.49
AK 586	0.62	0.54	0.63	0.57	0.59	2.10
AK 587	0.13	0.17	0.22	0.13	0.15	2.25
AK 588	0.37	0.45	0.52	0.47	0.45	1.94
AK 515	0.18	0.24	0.30	0.21	0.23	1.81
AK 536	0.32	0.39	0.43	0.35	0.36	2.62
*AK 467	(0.21)	(0.24)	0.29	(0.24)	0.29 (0.25)	1.84
*AK 468	(0.24)	(0.28)	0.33	(0.24)	0.33 (0.27)	1.54
*AK 469	(0.17)	(0.22)	0.27	(0.21)	0.27 (0.22)	1.98
*AK 470	(1.13)	(1.06)	1.20	(1.26)	1.20 (1.18)	2.45
*AK 471	(1.74)	(1.48)	1.62	(1.63)	1.62 (1.62)	2.59
*AK 472	(0.22)	(0.22)	0.27	(0.20)	0.27 (0.23)	1.79
*AK 473	(0.31)	(0.37)	0.44	(0.38)	0.44 (0.38)	1.79
*AK 450	(0.46)	(0.51)	0.54	(0.50)	0.52 (0.51)	2.34
*AK 466	-	-	0.57	-	0.57	-
*AK 474	(0.07)	(0.12)	0.12	(0.12)	0.12 (0.12)	3.45
*AK 440	(0.97)	(1.07)	-	(1.03)	1.02 (1.02)	2.31
*AK 514	(0.44)	(0.68)	0.46	-	0.46	-
*AK 447	(0.33)	(0.37)	0.43	0.43 (0.37)	0.43 (0.39)	1.83
*AK 453						
*AK 442	(0.38)	(0.42)	0.48	0.36 (0.36)	0.42 (0.40)	1.52

*x-r-f = percent K_2O obtained by x-ray fluorescence techniques.

*KTPB = percent K_2O obtained by the gravimetric techniques.

*Flame = percent K_2O obtained by the flame photometric method.

*Samples marked with an asterisk have:

(1) been discussed in a previous publication

or (2) been assigned a potassium-argon date by a person other than the author.

Sample	*x-r-f %		*KTPB %	*Flame %	Best K_2O %	Na_2O %
N 30° - 60°W Trend, Yellowknife Area (Set IV)						
AK 574	0.21	0.21	0.27	0.17	0.20	1.83
AK 575	0.29	0.33	0.37	0.33	0.33	1.39
AK 576	0.33	0.44	0.55	0.48	0.45	1.75
AK 578	0.78	0.75	0.90	0.86	0.82	1.67
AK 590	0.20	0.21	0.24	0.15	0.19	3.70
AK 591	0.05	0.05	0.06	0.04	0.05	0.71
AK 592	0.77	0.76	0.86	0.86	0.80	2.30
AK 593	0.05	0.15	-	0.11	0.10	1.56
AK 594	0.22	0.23	0.27	0.17	0.22	3.31
AK 523	0.20	0.24	0.30	0.20	0.22	1.95
AK 537	0.58	0.64	0.68	0.62	0.61	1.70
AK 589	0.09	0.09	0.13	0.05	0.09	4.38
AK 585	0.25	0.25	0.19	0.21	0.21	1.43
N 0° - 30°E Trend, Yellowknife - Lac de Gras Areas (Set II)						
AK 595	0.46	0.46	0.51	0.46	0.47	2.16
AK 596	0.05	0.07	0.09	0.05	0.07	4.40
AK 525	0.20	0.25	0.28	0.22	0.22	1.75
AK 527	0.81	0.80	0.88	0.94	0.86	3.72
*AK 465	(0.41)	(0.44)	0.51	(0.46)	0.51 (0.44)	2.01
*AK 439	(0.82)	(0.92)	0.96	(0.89)	0.96 (0.90)	1.66
*AK 441	(1.27)	(1.40)	1.49	1.31 (1.42)	1.40 (1.38)	2.43
*AK 449	(1.25)	(1.50)	1.39	1.36 (1.48)	1.38 (1.40)	2.47
*AK 474	0.07	0.12	0.12	0.12	0.12 (0.12)	3.45
AK 591	0.37	0.52	0.52	0.44	0.44	2.18
N 0° - 30°W Trend, Lac de Gras, Point Lake - Coronation Gulf Area (Set III)						
AK 597	0.51	0.45	0.53	0.46	0.50	2.49
AK 598	0.40	0.47	0.49	0.43	0.45	2.64
AK 599	0.90	0.84	-	0.98	0.91	2.20
AK 600	0.65	0.62	0.69	0.67	0.66	2.28
AK 604	1.62	1.31	1.54	1.64	1.54	3.33
AK 605	1.36	1.09	1.23	1.18	1.22	2.53
AK 609	1.61	1.40	1.64	1.65	1.59	3.17
AK 610	1.00	0.91	1.09	1.07	1.02	3.01
AK 613	0.60	0.58	0.65	0.62	0.60	2.51
AK 614	0.67	0.66	0.72	0.72	0.67	2.64
*AK 448	(0.63)	-	0.66	0.65 (0.69)	0.66 (0.66)	1.85
*AK 445	(0.75)	(0.83)	0.92	0.82 (0.87)	0.87 (0.87)	2.21
AK 513	(1.09)	(1.24)	1.34	1.35	1.35	-
*AK 444	(0.49)		0.68	0.57 (0.54)	0.63 (0.60)	2.35
*AK 452	-	-	0.94	-	0.94	-

Sample	*x-r-f %		*KTPB %	*Flame %	Best K_2O %	Na_2O %
Yellowknife Differentiated Intrusive						
BG 1 1887-1	0.88	0.80	0.83		0.83	2.87
Bu 2 1887-2	0.38	0.40	0.37		0.37	1.27
AK 463 UB	-		0.48	-	0.48	-
AK 464 G	-		1.36	-	1.36	-
AK 520 UB	-		0.60	-	0.60	-
N 30°E Trend, Coronation Gulf Area						
AK 602	0.82	0.76	0.84	0.80	0.81	2.83
AK 606	0.17	0.21	0.23	0.20	0.21	2.34
AK 608	0.21	0.26	0.29	0.21	0.22	2.20
N 10° to N 10°E Trend, Ontario						
AK 647	0.32	0.38	0.40	0.34	0.34	2.14
AK 648	0.50	0.55	0.60	0.78	0.53	2.44
AK 649	1.23	1.12	1.23	1.22	1.19	3.70
AK 650	1.33	1.13	1.24	1.26	1.21	2.98
AK 653	0.57	0.61	0.65	-	0.59	-
N 10° - 40°W Trend, Ontario						
AK 651	1.08	0.93	0.98	0.99	0.98	3.36
AK 616	1.58	1.26	1.43	1.31	1.37	2.96
AK 620	1.64	1.32	1.44	1.52	1.44	1.58
AK 621	0.76	0.70	0.75	0.72	0.73	2.80
AK 622	0.81	0.79	-	0.87	0.82	2.49
AK 607	0.67	0.56	-	0.51	0.58	2.81
AK 611	2.70	2.18	2.53	2.61	2.51	1.88
AK 615	0.64	0.60	-	0.64	0.65	2.94
N 50° - 80°E Trend, Ontario						
AK 652	0.15	0.16	0.30	0.12	0.16	2.20
AK 624	0.19	0.21	-	0.17	0.19	2.23
Sills, Ontario						
AK 619	1.76	1.42	-	1.65	1.62	3.63
AK 612	1.18	1.01	1.07	1.10	1.09	3.83

Total Alkali and Silica Content of Basic Dykes and Sills

Sample	Na_2O+K_2O	SiO_2	Sample	Na_2O+K_2O	SiO_2
N 70° - 80°E Trend, Yellowknife - Lac de Gras Areas (Set I)					
AK 579	2.6	49.2	AK 468	1.9	49.0
AK 581	2.0	47.3	AK 469	2.3	50.5
AK 582	3.1	50.4	AK 470	3.7	50.2
AK 583	4.1	49.4	AK 471	4.2	51.9
AK 584	4.5	50.3	AK 472	2.1	48.9
AK 586	2.7	48.1	AK 473	2.2	48.5
AK 587	2.4	48.8	AK 450	2.9	54.1
AK 588	2.4	50.0	AK 440	3.3	52.5
AK 515	2.0	49.1	AK 447)	2.3	49.7
AK 536	3.0	49.6	AK 453)		
AK 467	2.1	49.0	AK 442	1.9	51.8
N 30° - 60°W Trend, Yellowknife Area (Set IV)					
AK 574	2.0	48.3	AK 593	1.7	56.5
AK 575	1.7	48.0	AK 594	3.5	49.4
AK 576	2.2	48.2	AK 523	2.2	47.7
AK 578	2.5	48.2	AK 537	2.3	47.7
AK 590	3.9	50.3	AK 589	4.5	51.5
AK 591	0.8	53.4	AK 585	1.6	47.0
AK 592	3.1	51.9			
N 0° - 30°E Trend, Yellowknife - Lac de Gras Areas (Set II)					
AK 595	2.6	47.7	AK 439	2.6	47.3
AK 596	4.5	48.3	AK 441	3.8	48.3
AK 525	2.0	48.8	AK 449	3.9	46.5
AK 527	4.6	52.6	AK 519	2.6	50.9
AK 465	2.5	48.1	AK 474	3.6	50.0
N 0° - 30°W Trend, Lac de Gras, Point Lake, Coronation Gulf (Set III)					
AK 597	3.0	52.5	AK 610	4.0	50.8
AK 598	3.1	52.1	AK 613	3.1	51.4
AK 599	3.1	50.2	AK 614	3.3	53.7
AK 600	2.9	50.9	AK 448	2.5	48.8
AK 604	4.9	50.4	AK 445	3.1	52.0
AK 605	3.8	53.0	AK 444	3.0	48.8
AK 609	4.7	55.6			

Sample	Na_2O+K_2O	SiO_2	Sample	Na_2O+K_2O	SiO_2
Yellowknife Differentiated Intrusive					
BG-1	3.7	49.5			
BG-2	1.6	42.6			
N 30°E Trend, Coronation Gulf Area					
AK 602	3.6	46.8			
AK 606	2.6	50.6			
AK 608	2.4	47.6			
N 10°W to N 10°E Trend, Ontario					
AK 647	2.5	49.6	AK 649	4.9	48.6
AK 648	3.0	51.5	AK 650	4.2	51.6
N 10° - 40°W Trend, Ontario					
AK 651	4.3	45.8	AK 622	3.3	49.4
AK 616	4.3	50.8	AK 607	3.4	49.6
AK 620	3.0	47.9	AK 611	4.4	51.4
AK 621	3.5	48.7	AK 615	3.6	50.6
N 50° - 80°E Trend, Ontario					
AK 652	2.4	50.6			
AK 624	2.4	46.5			
Sills, Ontario					
AK 619	5.3	50.0			
AK 612	4.9	52.0			

Plate I. Photomicrographs of the Yellowknife Differentiated Intrusion*

Figure 1. DL-2. Contact of quartz gabbro and metasediments baked to a hornfels. Note long, narrow, laths of pleochroic biotite. Plain light. x25.

Figure 2. DL-27. Quartz gabbro, six inches from contact. Large pleochroic biotite flakes and some magnetite dominate a background of feldspar. Cloudy areas indicate alteration zones. Plain light. x62.5.

Figure 3. G-15. Quartz gabbro, 300 feet from upper contact with metasediments. Large crystals of fresh biotite occur closely associated with magnetite, together with rounded, altered grains of clinopyroxene and plagioclase. Light grey areas in plagioclase are sericitized. Opaque mineral is magnetite. Plain light. x 25

Figure 4. AK 464 (REF BG-116). Quartz gabbro. Large dark grain in lower centre is an altered pyroxene grain. Above this, quartz and feldspar form a granophyric intergrowth. A central lath of biotite and several hexagonal apatite crystals are present. Plain light. x62.5

Figure 5. UBS. Serpentine. Small pockets of fibrous serpentine form rosettes in cryptocrystalline, massive serpentine. Plain light. x62.5

Figure 6. BU-2 '47. Picrite. Serpentine veinlet cuts olivine grain (upper centre) and pyroxene grain (right centre). Olivine only is serpentinized adjacent to veinlet. Note few small biotite crystals. Plain light. x25

Figure 7. C-30. Picrite. Blocky olivine crystals poikilitically enclosed in large plates of pyroxene, with interstitial plagioclase and a few biotite flakes. Note curved fracture lines, mostly filled with serpentine. Plain light. x25

Figure 8. AK 520 (core C-158). Picrite. Large crystals of olivine and pyroxene with interstitial plagioclase. Smaller olivine crystals are partially enclosed by pyroxene. Plain light. x25

* see also Plate III, Figure 3.

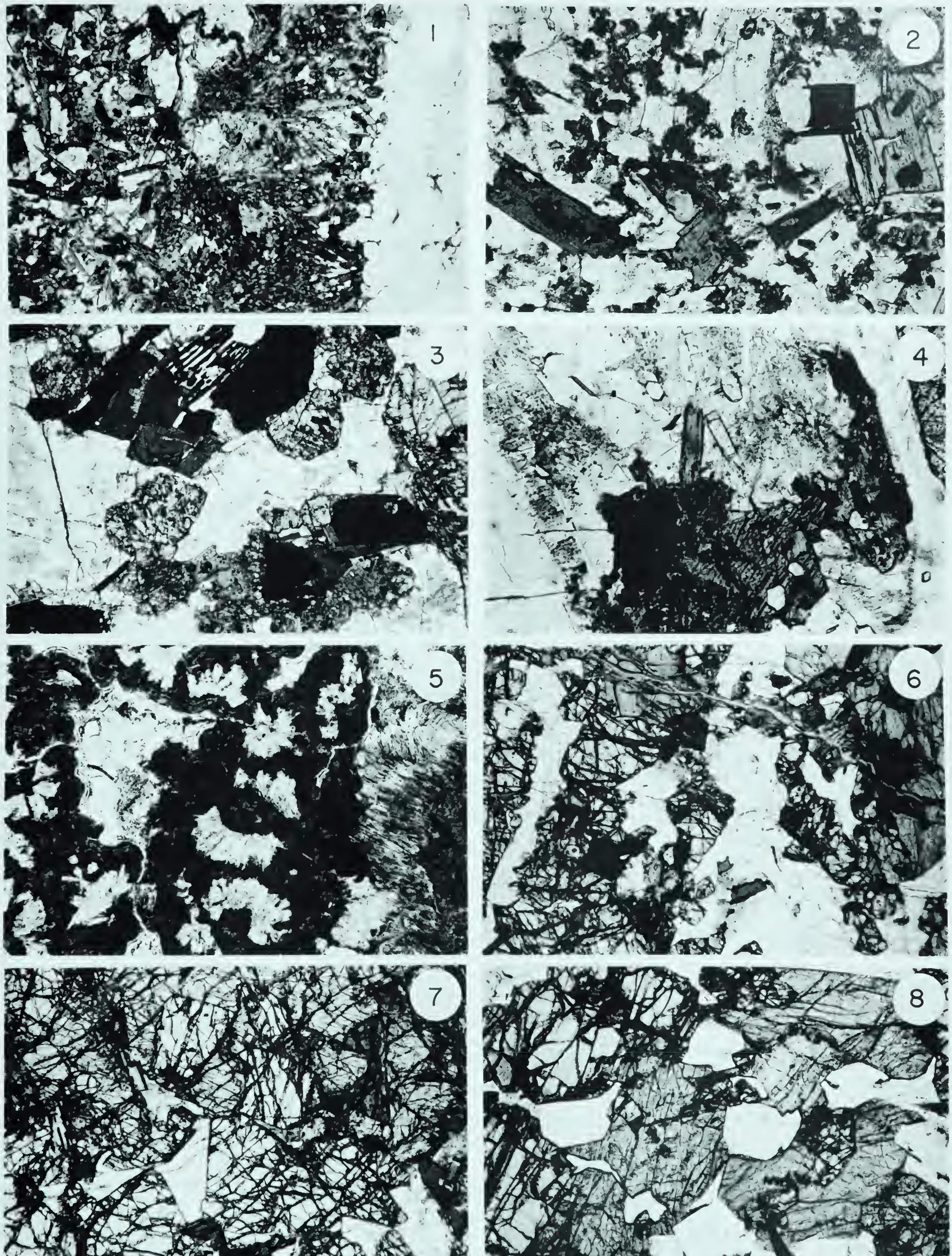


PLATE I.

Plate II. Photomicrographs of Diabase Dykes and Their Contact Zones

Figure 1. AK 613 (CG-12). Dyke contact. Phenocrysts of twinned pyroxene, serpentinized feldspar and unaltered feldspar in a glassy black matrix. Plain light. x62.5

Figure 2. AK 467 (RAB 4980a). Dyke contact with granite. Note recrystallization of granite at contact and alignment of sericitized feldspar laths parallel to the contact. X-nicols. x25

Figure 3. AK 586 (AVP-11). Dyke contact with basic volcanic rock. Blocky feldspars are altered to epidote (centres) and sericite (halos). Note alignment of plagioclase laths parallel to the contact. Plain light. x62.5

Figure 4. AK 617 (0-2). Amphibolite two feet from dyke contact, Sudbury. Fibrous amphibole, very fresh in appearance, and plagioclase are the two major constituents of the rock. Quartz is present as well. Plain light. x25

Figure 5. AK 523 (REF F-74). Two centimeters from dyke contact. Fine-textured basalt with conspicuous phenocrysts of olivine and plagioclase. Plain light. x25

Figure 6. CG-2. Two inches from dyke contact. An aggregate of twinned pyroxen lies in the upper left corner and a large olivine grain at the right edge. U-shaped patch of light minerals is a segregation of quartz and feldspar. Round crystals are biotite. Other phenocrysts are plagioclase laths. Plain light. x62.5

Figure 7. AK 469 (RAB 4980c). Dyke centre. Large plagioclase lath is idiomorphic towards the pyroxene, but not towards an altered olivine grain. Plagioclase is twinned according to the Albite,Carlsbad and Pericline laws, and the composition ranges from An 90 in the core to An 65 at the rim. X-nicols. x62.5

Figure 8. AK 469 (RAB 4980c) Dyke centre. Large plagioclase crystal, twinned according to the Albite and Carlsbad laws, shows zoning that becomes extreme on the side of the crystal adjacent to the granophyric zone. The large pyroxene crystal at the right ophitically encloses several plagioclase crystals. X-nicols. x25

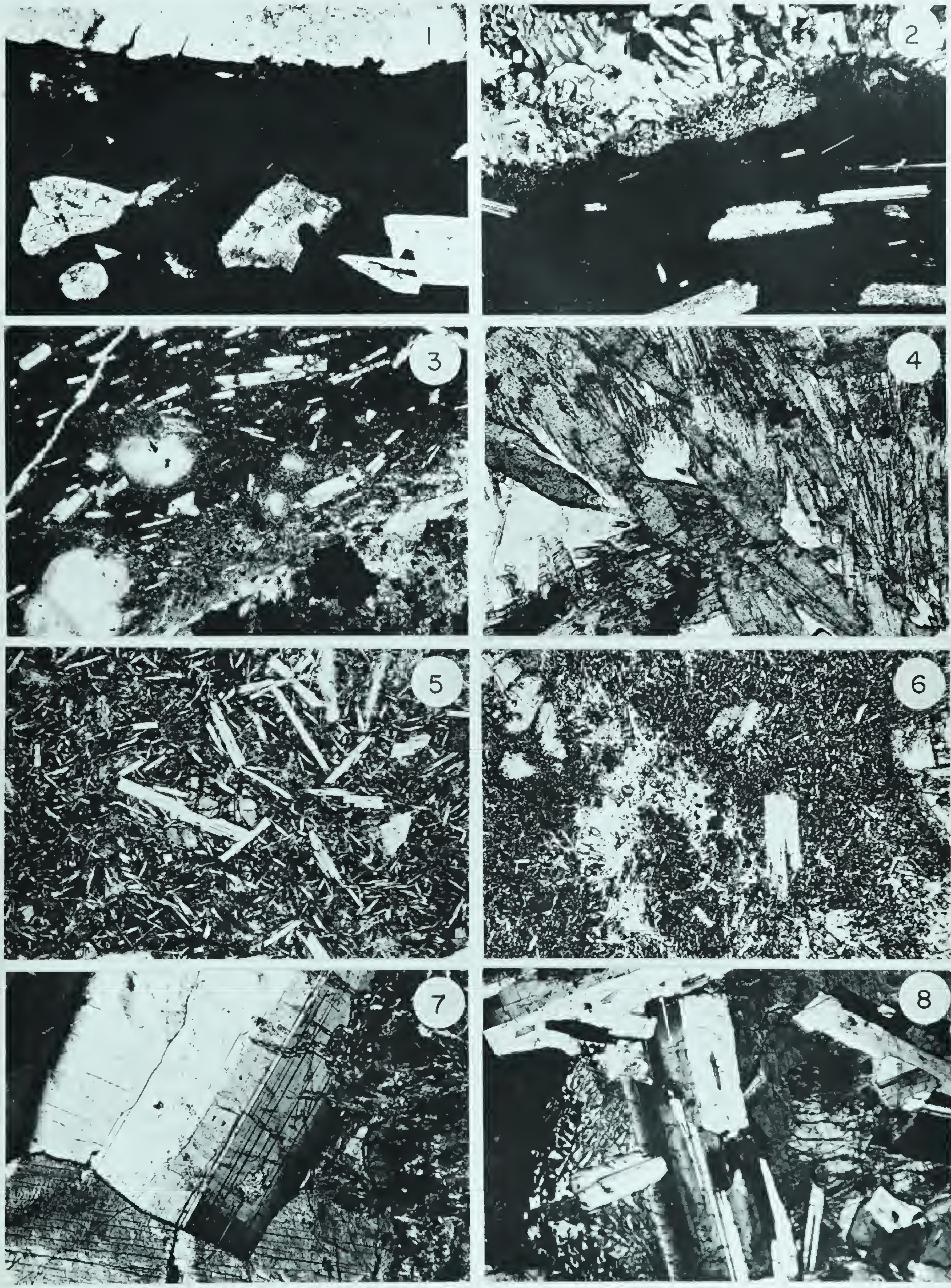


PLATE II.

Plate III. Photomicrographs of Diabase Dykes and Gabbro Sills

Figure 1. AK 468 (RAB 4980b). Dyke centre. Ophitic texture well-developed. Olivine crystals, zones and serpentinized, are enclosed with plagioclase laths in large, optically continuous pyroxene. Plain light. x25

Figure 2. AK 585 (CON 4 UG). Dyke centre. Relict olivine grains are altered to serpentine and iron oxide. Large plates of pyroxene enclose plagioclase lathes. Plain light. x25

*Figure 3. BG-1 '47. Quartz gabbro sill, lower part. Note large unaltered olivine crystal, the zoned pyroxene, and the quartz-feldspar intergrowth. The central plagioclase crystal shows Carlsbad twinning and has simple zoning. X-nicols. x25

Figure 4. AK 468 (RAB 4980b). Dyke centre. Two kinds of pyroxene, augite and pigeonite, both relatively fresh, look very alike. Plain light. x25

Figure 5. AK 595 (REF R-10A'65). Dyke centre. Large twinned pyroxene grains intergrown with well-twinned plagioclase laths. Pyroxene in lower right has been serpentinized. X-nicols. x62.5

Figure 6. AK 602 (CG-3). Dyke centre. Pyroxene is altered to fibrous amphibole. Note abundant granophyre. Plain light. x62.5

Figure 7. AK 441 (REF A-89'48). Dyke centre. A twinned pyroxene crystal, altered to serpentine (dark zone) encloses apatite and plagioclase. Sericitized plagioclase crystals border the pyroxene to the upper right, and some quartz is found on the left. Plain light. x62.5

Figure 8. AK 445 (REF A-29'48). Dyke centre. Clear areas are mostly quartz. Note needles of rutile and small apatite crystals. Twinned altered pyroxenes form a cluster to the upper right. Plain light. x62.5

* Yellowknife differentiatedintrusion

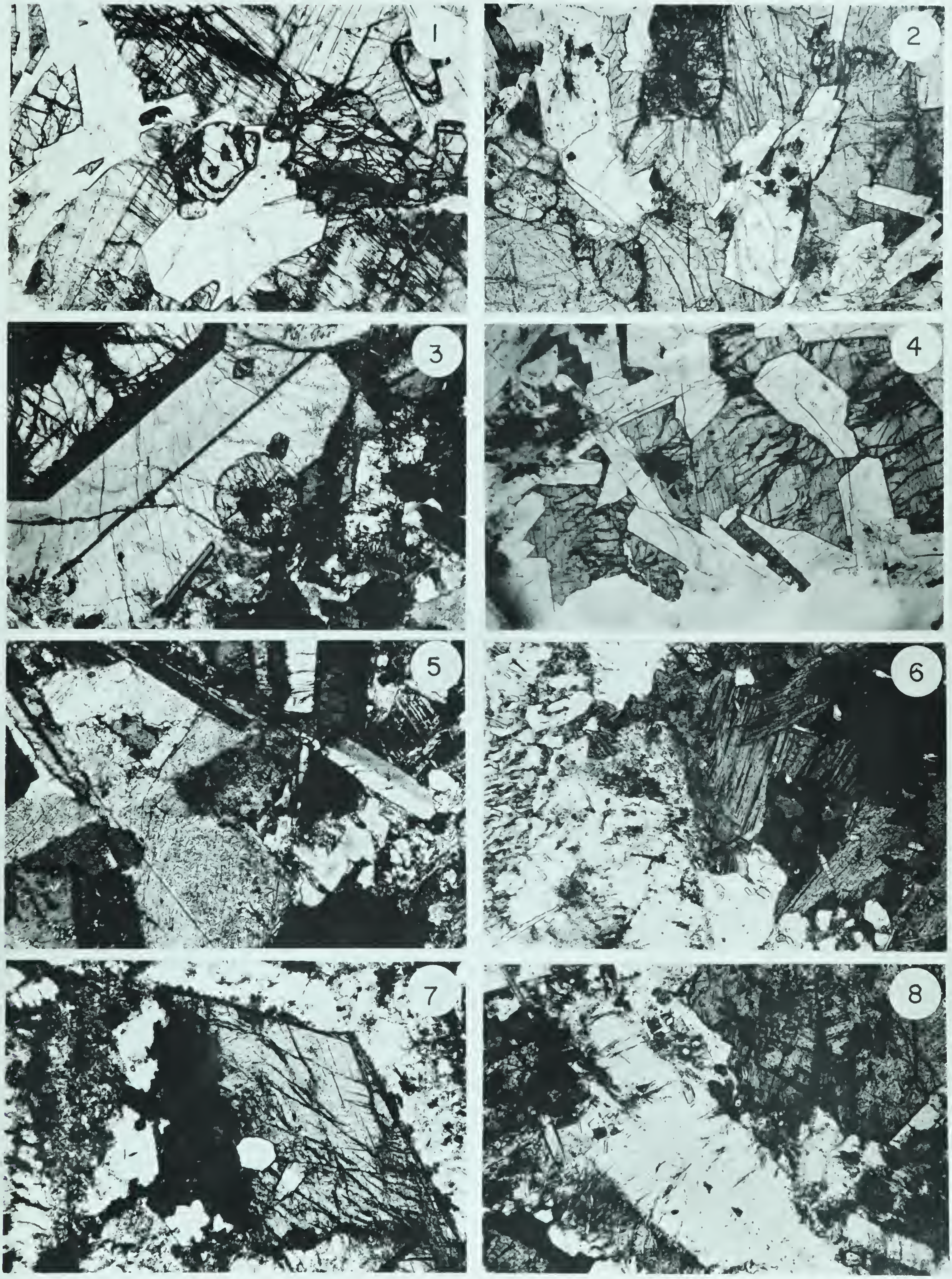


PLATE III.

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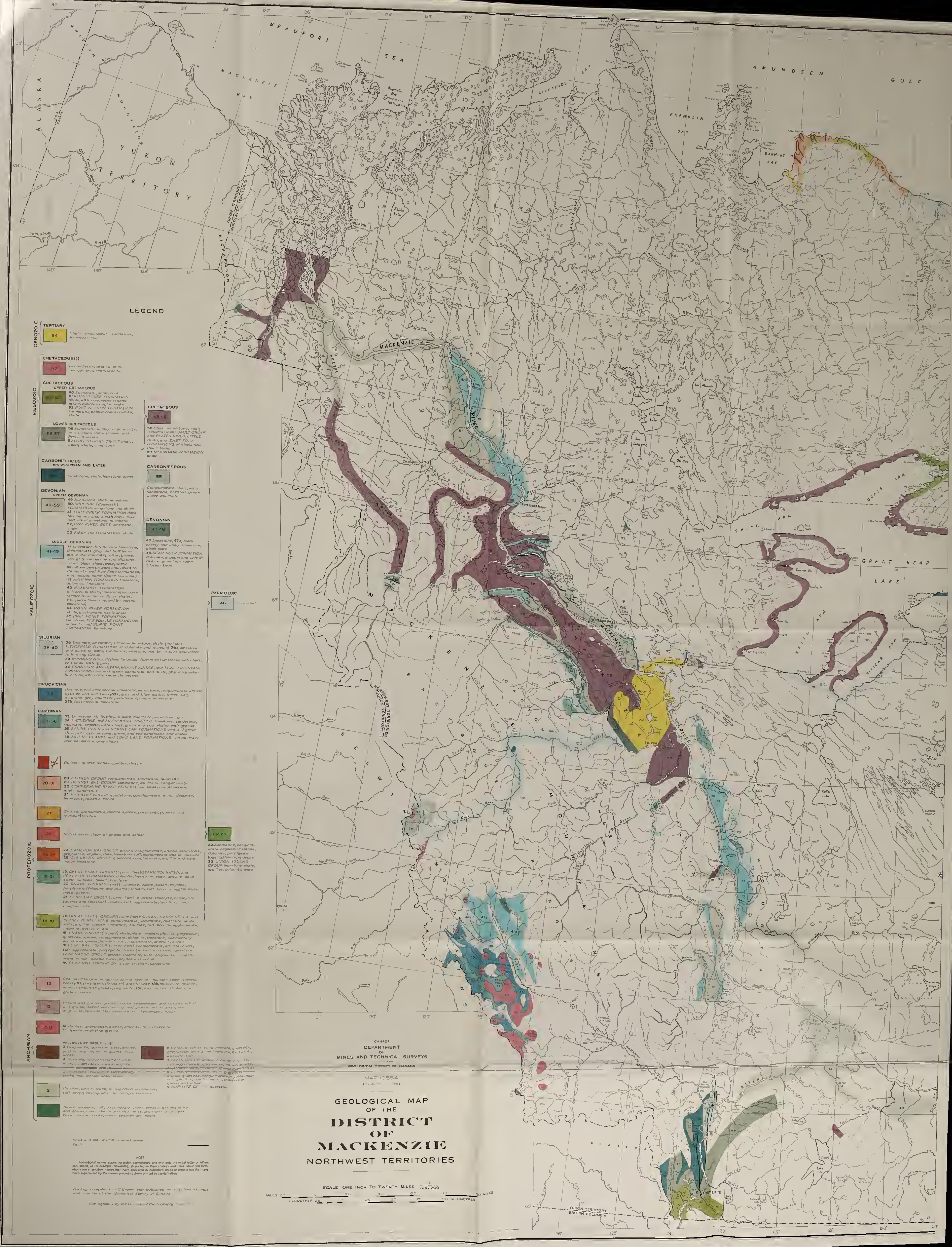
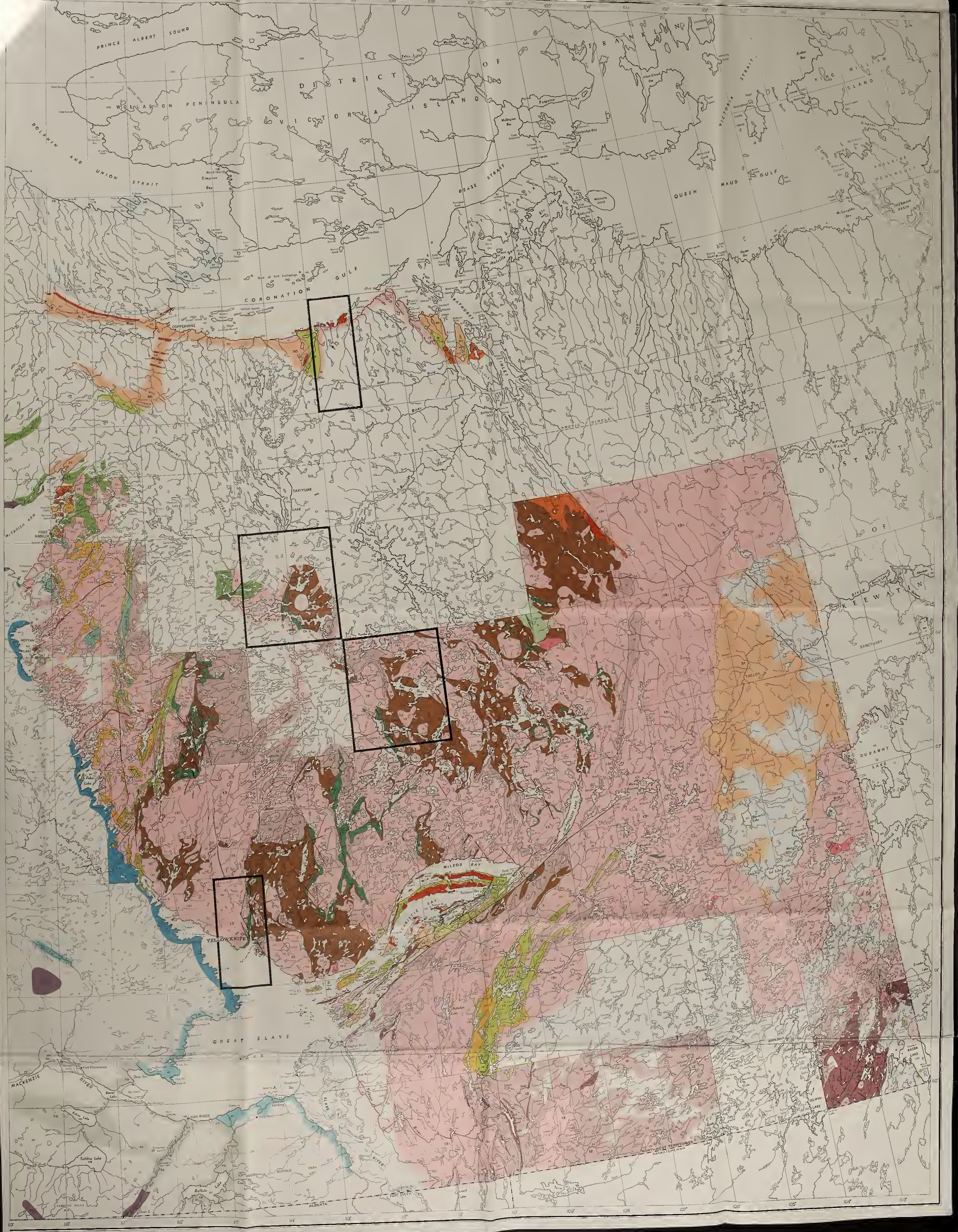
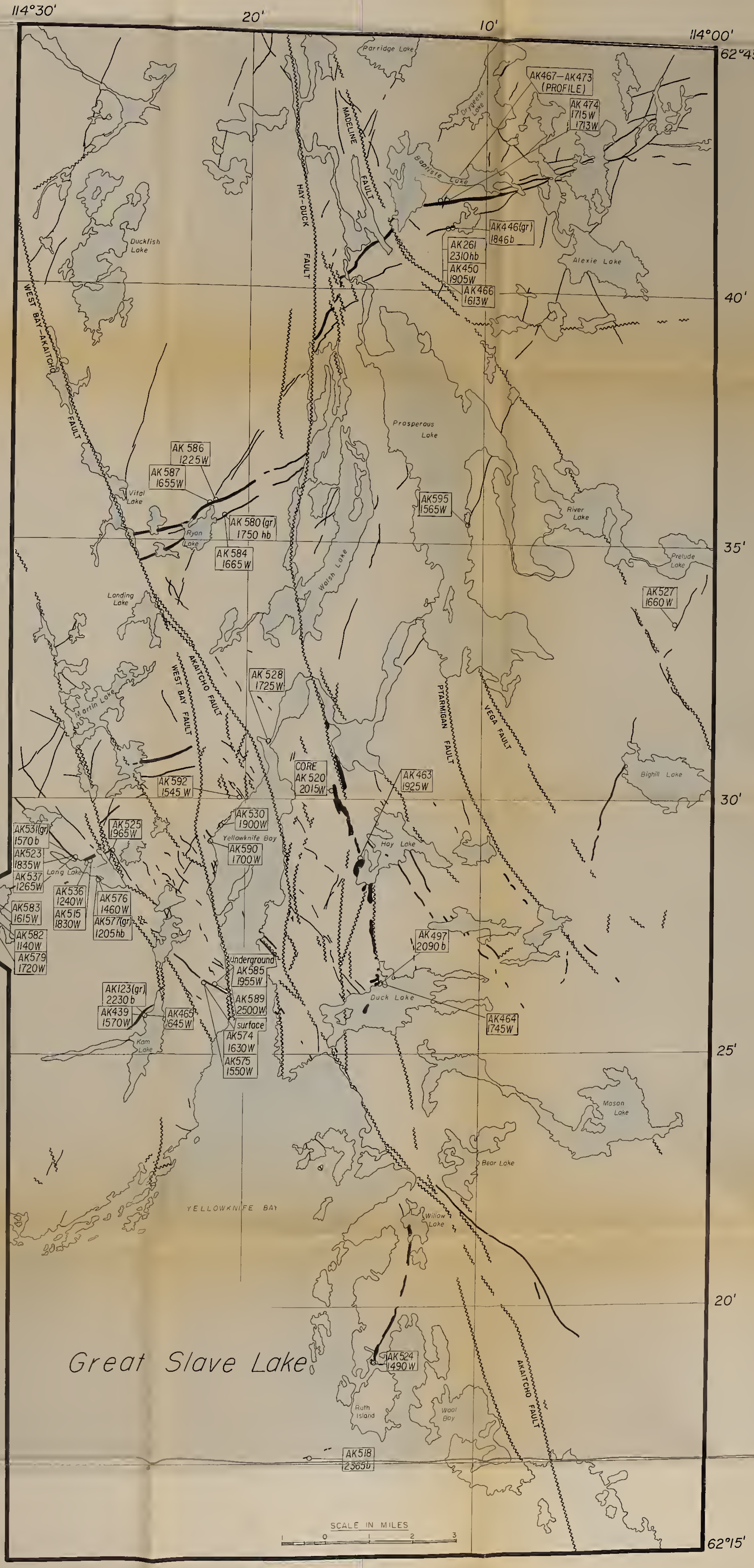


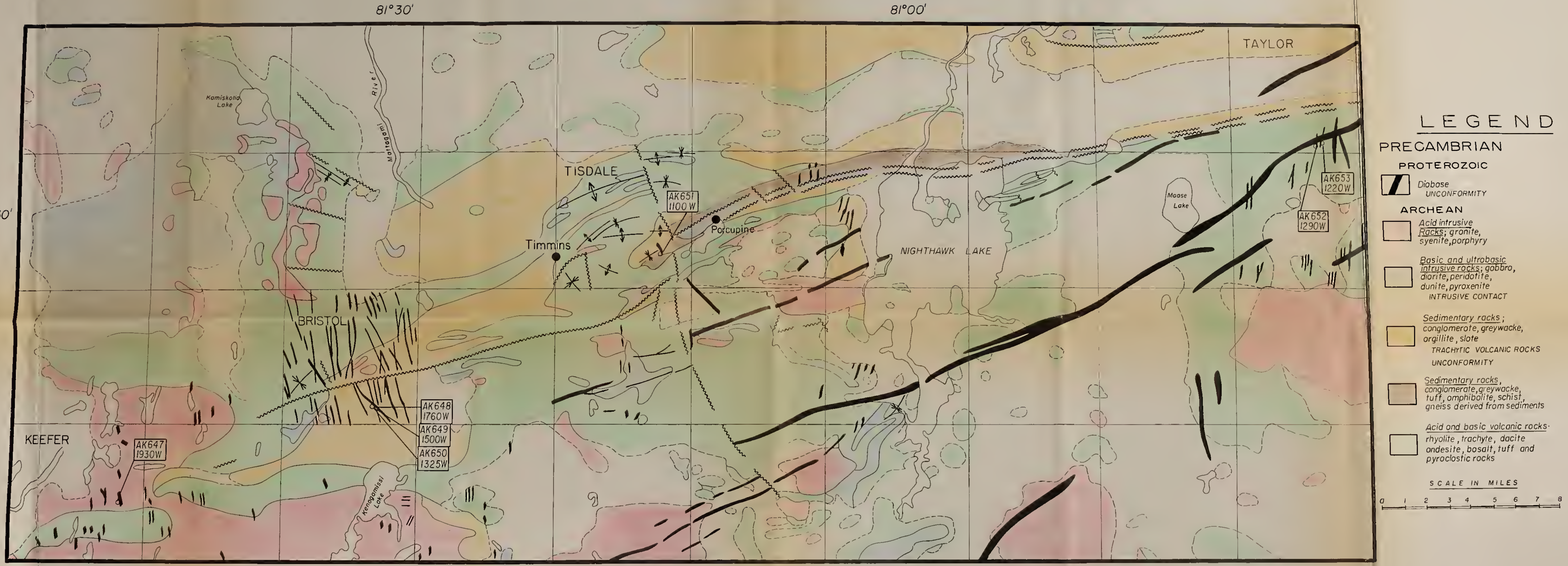
BEAUFORT SEA
AMUNDSEN GULF
FRANKLIN BAY
DARNLEY BAY
LIVERPOOL BAY
MACKENZIE BAY
ALASKA
YUKON TERRITORY
GREAT BEAR LAKE
SMITH ARM
DEASE ARM
KEITH ARM
MCVICAR ARM
MACKENZIE
LEGEND
CENOZOIC
TERTIARY
MESOZOIC
CRETACEOUS(?)
CRETACEOUS
UPPER CRETACEOUS
LOWER CRETACEOUS
CARBONIFEROUS
MISSISSIPPIAN AND LATER
DEVONIAN
UPPER DEVONIAN
MIDDLE DEVONIAN
PALÆOZOIC
SILURIAN
ORDOVICIAN
CAMBRIAN
PROTEROZOIC
ARCHÆAN
CANADA
DEPARTMENT
OF
MINES AND TECHNICAL SURVEYS
GEOLOGICAL SURVEY OF CANADA
MAP 1055A
GEOLOGICAL MAP
OF THE
DISTRICT
OF
MACKENZIE
NORTHWEST TERRITORIES
SCALE ONE INCH TO TWENTY MILES = 1/1,267,200
MILES
KILOMETRES
NOTE
Formational names appearing within parentheses and with only the initial letter or letters capitalized, as for example (Bosworth), (Hare Indian River shales), and (Bear Mountain formation), are alternative names that have appeared in published maps or reports but that have been superseded by the names preceding them printed in capital letters.
Fault
YUKON TERRITORY
BRITISH COLUMBIA



PRINCE ALBERT SOUND
WOLLASTON PENINSULA
DOLPHIN AND UNION STRAIT
DISTRICT OF FRANKLIN
VICTORIA ISLAND
DEASE STRAIT
QUEEN MAUD GULF
VICTORIA STRAIT
KING WILLIAM ISLAND
CORONATION GULF
COPPERMINE
ARCTIC CIRCLE
DISTRICT OF KEEWATIN
SANCTUARY
THELON
DUBAWNT LAKE
McLEOD BAY
YELLOWKNIFE
GREAT SLAVE LAKE
MACKENZIE RIVER
HAY RIVER
FORT SMITH
ALBERTA
NORTHWEST TERRITORIES
SASKATCHEWAN



YELLOWKNIFE — PROSPEROUS LAKE AREA
(after A. W. Jolliffe)



PORCUPINE — TIMMINS AREA
(after O. D. M. Map 2046)